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# Application of Multi-Criteria Analysis selecting the most effective Climate change adaptation measures and investments in the Italian context

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**Abstract.** In the context of climate change, one of the EU's major political efforts focus on water management. Public investment is carried out considering several drivers, from economic development to demographics, climate, and pollutants. Meanwhile, the need for evaluation methods is also increasing, so their development has grown in recent years. Among these, Multi-Criteria Analysis methodologies (MCA) have taken on great importance. This work aims to demonstrate the usefulness of MCA in addressing crucial environmental issues, such as the use of water resources for agricultural and food production. The document presents an application of MCA for the ranking and selection of projects to be financed under the Italian National Plan on Water Resources. The Plan is part of the national initiatives planned for the adaptation of the agricultural sector to climate change. The selection criteria have been identified following a participatory approach, and to respond to both the challenge of climate change and the limited availability of funds. MCA is used to select the best projects to be financed with the available amount. The Italian experience confirms the effectiveness of MCA and highlights how the involvement of both decision makers and stakeholders is necessary for a successful application of MCA to environmental issues.

**Keywords:** drought risk, water management, investment database, reservoirs, climate change.

## 1. INTRODUCTION

In recent decades, climate change has caused worrying drought events across Europe, even in Countries where past meteorological drought had been rare. This situation has led EU Member States to monitor the availability of and need for water, to provide timely alerts in the event of drought and identify possible actions to undertake in the event of a crisis. Recent studies carried out on the Italian territory have shown a growing climate heterogeneity due to climate change (Zucaro, 2017; ISPRA, 2018). In the past, drought events



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were mainly concentrated in the Southern Regions and Islands, while, in the last 20 years, Central and Northern Italy have also suffered from recurrent droughts.

The agricultural sector is the most exposed to the effects of climate change (Mahato, 2014), there is therefore a need for targeted investments increasing the preparedness to face extreme events. As floods and droughts affect both the quantity and quality of water, they contribute to environmental degradation and loss of ecosystem services. Thus, all Member States (MSs), including Italy, are implementing adaptation and mitigation measures. International institutions, and in particular the European Union (EU) are steering their policies and economies towards long-term sustainability. In recent years, there has been a crescendo in the political narrative aimed at promoting climate change adaptation and mitigation. Several actions have been proposed to implement these policies, namely: enhancing knowledge in the field of climate change adaptation and mitigation policies (EU Adaptation Strategy, European Commission, 2013); managing water risks and disasters; ensuring good water governance and sustainable investment for water services (OECD, 2015, ODEC 2016); encouraging the sustainable use of water for agriculture and the introduction of priority actions for the adaptation of agriculture to climate change (FAO – WASAG Global Framework for Action to Cope with Water Scarcity in Agriculture); taking account of climate adaptation in public and private investments (European Green Deal, European Commission, 2019).

Several measures, singly or in combination, can be taken to cope with drought risk in agriculture, climate change adaptation, and sustainable water management. These include regulatory measures, risk management measures, water governance, research and innovation, and structural measures. There is no single decisive action, but the most effective one or a combination of them should be taken. Public investment in water distribution infrastructure allows for greater and more constant availability of water for irrigation and greater efficiency in water use, by reducing water abstractions, introducing instruments for water metering, and increasing the use of non-conventional water. These investments can also contribute to achieving the objectives of the Water Framework Directive (WFD, 2000/60/EC) of ensuring the availability of quality water for the needs of people and the environment. This is possible through the improvement of the ecological quality of water bodies and the conservation and restoration of areas of naturalistic interest (e.g. Nature 2000 sites).

At the European level, specific funds have been allocated to finance irrigation investments as a response to the water crises of 2003 and 2007. These investments aimed to increase water storage and irrigation efficiency, through the modernization of existing assets, the building of new reservoirs, and the recovery and improvement of existing ones. To decrease the dependency on conventional sources and reduce withdrawals from natural water bodies, the promotion of the reuse of treated wastewater for irrigation purpose is also pursued.

In Italy, with the aim of ensuring the integrated management of water resources, a steering committee has been set up to coordinate the various administrations responsible for water: the Steering Committee addressing investments in cross-sectoral investments, responding to the recommendations of the European Commission communication "Addressing the challenge of water scarcity and drought in the European Union" (COM, 2007) 414 final).

Following this strategy, in 2017 the Italian Government financed the "National Plan of interventions in the Water Sector" (Budget Law 2018, December 27, 2017, No. 205). The National Plan was finalized to modernize and complete the national water distribution network (including the irrigation network) and to build new reservoirs. The National Plan also foresaw the adoption of an *Extraordinary Plan*, consisting in the implementation of urgent interventions against drought, with a focus on multipurpose reservoirs.

At the River Basin scale, reservoirs are considered as effective climate change adaptation measures, especially where natural water availability is highly variable throughout the year. In fact, they retain water to be released during periods of scarcity, thus sustaining irrigated agriculture and increasing the availability of water for irrigation (Biemans, 2011). In addition, reservoirs have ecological and recreational functions, ranging from the conservation of protected migratory species (Mascara, 2010) and biodiversity (Deacon, 2018, Croce, 2015), to cultural and recreational purposes. That is why some of them are now defined as natural conservation areas.

The case study shows the procedure followed by the Council for Agricultural Research and Economics (CREA), on behalf of the Italian Ministry of Agriculture (Mipaaf), in selecting interventions to help the agricultural sector adapt to climate change. The interventions were selected according to the objectives of the *Extraordinary Plan* applying a Multi-Criteria Analysis (MCA). MCA is a non-monetary method of ranking and prioritizing the characteristics of the projects submitted for funding.

The paper aims to present the feasibility and usefulness of MCA in identifying the most effective project proposals in the field of water, stating that this method

can allow the inclusion of different disciplines in a single evaluation frame. In addition, MSs need appropriate methods to assess *ex ante* effectiveness of investment projects, including their potential impacts on natural resource protection. The Italian experience can therefore be extended to other countries.

## 2. DATA AND RESEARCH METHODOLOGY

### *2.1 Multi-Criteria Analysis*

Multi-Criteria Analysis (MCA) was selected as a method for classifying and selecting projects, as it allowed consideration of the different priority elements according to the requirements by the funder, and the needs in term of adaptation to climate. MCA was considered the appropriate method as it allowed several specific agricultural and environmental conditions to be applied (Figueira et al., 2005). This facilitates the achievement of increased efficiency and sustainability in the use of natural resources in line with the EU guidelines.

Several papers have been published over the last 30 years on the empirical applications of MCA to a range of nature conservation topics, including: conservation priority and planning; management and zoning of protected areas; forest management and restoration; mapping of biodiversity, naturalness, and wilderness. Many references can be found in several reviews, such as: Mendoza et al. (1986); Romero and Rehman (1987); Tarp and Helles (1995); Hayashi (2000); Kangas et al. (2001); Steiguer et al. (2003); Mendoza and Martins (2006).

A recent and extensive review of the applications of Multi-Criteria Decision Analysis was carried out by Adem Esmail and Geneletti, (2017), based on 86 papers and dealing with empirical applications in nature and biodiversity conservation. Decision-making in environmental management requires more and more comparison alternatives to achieve multiple and competing goals. Indeed, many of the following objectives must often be considered: ensuring a sufficient quantity of water for both people's needs and the environment (Water Framework Directive – implementation of the Water Framework Directive), economic development, addressing the challenges posed by demographic change, climate change, and emerging pollutants. The public administrations responsible for determining and evaluating strategic choices need systems and/or selection criteria that are as objective as possible and not influenced by endogenous factors. This problem is particularly acute when it comes to public funding.

In this context, Multi-Criteria Methodologies have become important because they provide valuable help in choosing between alternatives, especially since the classic economic and monetary surveys do not represent the plurality of aspects that these problems present (Skonieczny et al, 2005). Compared to monetary methods based on welfare economy principles (Cost- Benefit Analysis, CBA), non-monetary methods that also consider natural resources and are based on decision theory are an alternative when assessing the effectiveness of the interventions. While CBA is mainly applied to project evaluation to improve a specific environmental service, non-monetary methods such as MCA are used for issues related to territorial and environmental assessment and planning, as they can also evaluate qualitative information. Currently, several books deal with Multi-Criteria methodologies as applied to natural resources management (e.g. Zeleny, 1984; Yoon and Hwang, 1995; Malczewski, 1999; Belton and Stewart, 2002).

Basically, MCA is applied with the following typical steps:

1. Structuring of the problem and the decision-making network.
2. Data acquisition and processing.
3. Normalization (linear normalizations or Value and Utility functions).
4. Criteria and weight allocation.
5. Calculation and sorting of alternatives (e.g. with outranking methods; graphic methods; scoring methods).
6. Results.
7. Sensitivity analysis (optional).

The next paragraph describes how these steps were applied to the case study.

### *2.2. Applied methodology*

In this study, the listed steps of the Multi-Criteria Analysis were slightly reformulated, as follows.

*1. Structuring of the problem and the decision-making network*. There are many MCA approaches that differ in terms of computational complexity, level of stakeholder engagement and time and data requirements.

To protect the agricultural sector against drought events, policymakers identified structural measures, concerning infrastructure interventions on multipurpose reservoirs for water collection during rain periods and water saving interventions. A specific fund has been set up to these objectives, governed by specific rules.

Water management operates within an interdisciplinary framework that seeks to ensure the protection of resources (Cugusi and Plaisant, 2019; Dir. 2000/60/EC; Dlgs 152/1999; Autonomous Region of Sardinia, 2005), and requires the integration of ecological, economic,

and socio-political elements of different territorial scales. Therefore, all the institutions responsible for water management (Ministries of Agriculture, Environment, Infrastructure, Regions and River Basin District Authorities (RBDAs)), Local Agencies for irrigation Water Management (LAWMs), and stakeholders were involved in the decision-making network of this case study. The involvement of the stakeholders was a selling point in the methodology adopted by the CREA.

*2. Data acquisition and processing.* For the collection of data useful for the analysis, the CREA, Mipaaf, and Regions with the support of the LAWMs, identified the infrastructure priorities to be financed through national and EU resources. All information was stored and managed by DANIA, the National Database of Investments for Irrigation and the Environment (http://dania.crea.gov.it/). It was implemented by the CREA for Mipaaf, for the collection of structural and financial information on financed and programmed projects. Information about investments were provided by Regions and by SIGRIAN, the National Information System for Water Resources Management in Agriculture (https://sigrian.crea.gov.it) managed by the CREA (Mipaaf, 2015). SIGRIAN contains data from the Italian national irrigation system and is the national reference database for the collection of data on water used for irrigation on a national scale. In this work, SIGRIAN was used to collect information on the use of water resources and the extent of the irrigated area affected by the projects for the estimation of the catchment area. Starting from DANIA information, MCA was applied to identify a series of projects to be financed up to the amount of 80 million euros, allocated by the *Extraordinary Plan*.

*3 - 4. Criteria and weight allocation and normalization.* The criteria and their weights, as well as related attributes and scores were defined in compliance with the requirements and objectives of the financing instrument, by a technical committee of experts through focus group discussions. The focus group involved representatives of the aforementioned institutions, in the application of a participatory approach. Through debates between the actors of the technical committee, shared choices were developed. The participatory approach minimized decision makers' subjectivity in weight and score allocation, which is a very important and delicate step. Indeed, it can influence the final order of alternatives and, therefore, significant involvement is appropriate. Within the Technical Committee, the criteria were defined in accordance with the objective and priority of the Fund. Once the criteria were decided, several possible attributes for each criterion were defined. At first, the normalization step was bypassed in this case study. Since the main aim of normalization in MCA is to make quantities comparable, this was achieved by using nominal attribute quantities, to which scores must then be assigned.

The different attributes of the criteria were sorted according to their compliance with the selection aims. The weight of the criteria and the score of the attributes were assigned at the same time. Applying a monotonically linear utility function, a discrete scoring scale was adopted, with a step of 1, in all the criteria. In a descending way, a maximum score was assigned to its best attribute and a lower score was assigned to the other attributes, according to the preferences of the technical committee, and with reference to the selection goals. In this way, the weight of a given criterion coincides with the highest score assumed by its best attribute. Attribute scores ranged from 0-1 to 0-4, while the weights assigned to the criteria ranged from 1 to 4. With this operative choice, the discretions and uncertainties implied in weights were shifted to the definition of scores. For this reason, the technical committee verified that the highest score of each attribute truly represented the weight that the individual criterion should have had compared to the others.

*5. - 6. Calculation and sorting of alternatives and examination of results.* The ranking of alternatives, namely the projects, was achieved by applying a scoring method as a type of aggregation. The scoring method classified the alternatives by assigning a numerical evaluation for each of the attributes considered; the scores obtained for each criterion were summarized in a "summary indicator" which aimed to represent the effectiveness of the proposal in achieving the objectives of the Fund. The number of projects financed was the maximum obtainable on the basis of the defined budget allocated by the Budget law. The direct assignation of a value to the attribute and the use of a linear aggregation method with scores simply added together, have made the method used for the evaluation of the proposal clearer to the potential beneficiary. Consequently, even the self-assessment required in the submission phase of the projects was more feasible. Self-assessment was introduced because the RBDA was called upon to prioritise proposals, mainly based on the declared information.

*7. Sensitivity analysis.* The shared approach gave a certain degree of robustness, as the steps of criteria and weight allocation were based on the expert judgment of the technical committee. The order of importance of criteria and attributes was considered clear and objective, as it was shared among all the stakeholders. Nevertheless, in this study sensitivity analysis was carried out to verify the stability of the results, testing some changes in the weight of criteria (Skonieczny G. et al. 2005). New

weights were allocated to the criteria in compliance with the aims and rules of the Fund and without upsetting the priorities established by the technical committee.

To perform sensitivity analysis, as first step, the attribute scores were normalized to the maximum value that each attribute could assume (maximum row normalization), so that all the attribute scores are between 1 and 0. Then, Weighted Linear Combination (WLC) was used (Malczewski and Rinner, 2015) for the aggregation. Following equation 1, the normalized value of attribute score ($x_i$) was multiplied for the tested weights ($w_i$), and the new summary indicators (S) were returned for each alternative.

$$S = \sum w_i x_i \quad (1)$$

The new rankings of the alternatives, given from the different tested weight assignments, were compared with the original ranking by means of the Spearman's rank correlation coefficient, that is a non-parametric measure of rank correlation, following equation 2 (Clef, 2013):

$$\text{rho} = \sum_i (x_i - \bar{x})\,(y_i - \bar{y}) \,/\, \sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2} \quad (2)$$

where i = paired score, x and y are the ranks, and x-bar and y-bar are the mean ranks. The analysis of the results was carried out taking into account that the Spearman correlation between two variables is high when observations have a similar rank, up to a correlation of 1 for identical ranks.

## 3. RESULTS AND DISCUSSION

This section describes the detailed application and results of each step described above.

### *3.1 Structuring of the problem and of the decision-making network*

The case study concerned the application of MCA when selecting infrastructure interventions to facilitate adaptation of the agricultural sector to climate change.

The financial instrument identified was the *Extraordinary Plan* as part of *National Plan of interventions in the water sector*. It was introduced by the Budget Law 2018 to finance urgent interventions concerning: preferentially executive projects (the final phase of the project was also accepted); multipurpose reservoirs; water saving in agricultural and household use.

The decision-making network identified included the competent Ministries of Infrastructure (MIT), Environment (MATTM) and Agriculture (Mipaaf), the 7 RBDAs, the 21 Regions and Autonomous Provinces, and the LAWMs.

According to Italian legislation, the Regions are responsible for irrigation water management and reclamation, while the LAWMs, reclamation and irrigation consortia, and land improvement consortia are territorial authorities and actuators of the interventions.

### *3.2 Data acquisition and processing - the Database*

At the time of the study, DANIA included 894 irrigation infrastructure projects, representing almost 6 billion euros. Information was collected in the database for each project for their evaluation, in accordance with the established criteria. The stored data were acquired in collaboration with Regions and processed with identification data (title, actuators, etc.), technical features of projects (project objective and type, project stage, etc.), intervention cost, vulnerability of the intervention area to drought and hydrogeological risk, regional priority of intervention (1-high, 2-medium, and 3-low).

Starting with the stored projects, a first selection was made before applying the MCA according to the following eligibility criteria, in line with the Budget Law objectives and in the framework of financing fund rules:

- project stage = executive (because quickly implementable);
- type of intervention = interventions on multipurpose reservoirs and water saving interventions in agriculture;
- regional priority of intervention = level 1 (urgent interventions).

A dataset of 55 projects was identified on the entire national territory, representing a total amount of almost 360 million euros. The RBDAs were asked to give priority to projects in this dataset, to which MCA was applied.

### *3.3 Criteria and their attributes*

Some of the adopted criteria related to technical elements and aims of projects, while others referred to effectiveness, in compliance with the aim and priority of the Fund, as established in Law 205/2017.

As mentioned, the *Extraordinary Plan* dealt with multipurpose reservoir (irrigation and household) and the priority water saving objectives. More in detail, the Plan includes a) completion of interventions concerning large existing dams or unfinished dams; b) recovery and expansion of the reservoir capacity, waterproofing of large dams and safety of the main water derivations for significant river basins in seismic areas classified in

zones 1 and 2 and at high hydrogeological risk. As a result, the following project criteria were identified:

- *Water resource use*. Multiple uses were favoured over exclusive ones.
- *Site sensitivity in terms of seismicity and hydrogeological instability*. Great importance was given to the presence of these hazards. One of the priority objectives was identified as safety in seismic areas (classified in zones 1 and 2) and in areas of high hydrogeological risk. The technical committee decided to assign more importance to areas at seismic risk than to the landslide. Therefore, the same value was associated with the presence of hydrogeological risk and the presence of the lower class of seismic risk (fourth class). Increasing importance was given to other seismic classes, because of the growing risk.
- *Catchment area in Equivalent Inhabitants* – EI (given 40 Equivalent Inhabitants –per irrigated hectare). This criterion intended to indicate the impact of the project on the territory in term of users of financing (population or agricultural areas). Three classes were created for this continuous variable (EI > 500,000; 300,000 ≤ EI ≤ 500,000; EI < 300,000), both based on expert assessment, and on assessments based on the DANIA dataset. In addition, it was necessary to provide a unique criterion for household, irrigation, and multiple interventions. Thus, the irrigated area was returned to the EI, with a conversion criterion of 40 EI per hectare of irrigated surface.
- *Project stage*. The attributes represented the possible status of the project. The *Extraordinary Plan* focused on the final and executive level.
- *Project objectives*. This criterion aimed to select projects compliant with fund objectives. So, completion of existing dams and the recovery or extension of the reservoir capacity were among the priority objectives. In addition to these, a third class was created for projects aimed at the improvement of the derivation efficiency.
- *Project type*. This criterion integrated the technical information agreed in the previous one, detailing the specific type of intervention. The following attributes were identified: Securing; Extraordinary maintenance; Completion; New intervention.
- *Co-financing*. This was considered a reward element by the Technical Committee to promote Public-Private partnership.
- *Possibility of subdivision into lots*. This was considered a reward element by the Technical Committee, since it made it possible to assess the multiple financing of a project, even with different funding sources at different times.

In addition, three effectiveness criteria were identified, as follows.

- *Project effectiveness* (ratio of the intervention cost to the number of equivalent inhabitants corresponding to the irrigated area covered by the project: project cost (€)/EI). The criterion was described in 3 classes, namely < 25€/EI, >=25 €/EI <50 €/EI, >=50€/EI. They were created according to the evaluation by experts, also through the DANIA.
- *Territorial effectiveness*. This reflected a classification of the Italian Regions in relation to the percentage of their regional territory under risk of desertification; according to the scientific reference available for the national scale (Ceccarelli et al., 2006), 3 classes were adopted, namely: >40% very sensitive danger (Basilicata, Marche, Molise, Puglia, Sicily and Sardinia); > 40% moderately sensitive danger (Abruzzo, Campania, Emilia-Romagna, Lazio, Piedmont, Tuscany, Umbria and Veneto); little sensitive (other Regions).
- *District priority*. This was the assessment provided by the RBDA on the effectiveness of the project, in the context of the specific River Basin Management Plans. This criterion was considered by the Technical Committee to be the most important of the effectiveness criteria, as it was evaluated through expert assessment by each RBDA and summarised several environmental aspects. In particular, each RBDA established their priority based on the information listed above and considering the objectives of the Water Framework Directive (2000/60/EC) and the main issues in the National Plan. For the estimation of District priority, the factors considered were:
  - consistency with another District Plans;
  - criticality of the intervention area, such as the hydraulic risk level; hydro-morphological aspects; environmental pressures;
  - expected benefits in terms of pressure reduction on water bodies;
  - expected benefits in terms of improving the water balance at river basin level.

The level of effectiveness dealing with the strategic environmental feature, was described with four attributes: Strategic, Relevant, Important, Required.

### *3.4 Weight and score allocation*

The weights assigned to the criteria are shown in Table 1. The criteria with the highest weight were: district priority, seismicity degree, project type, and project stage (weight 4). They were of equal importance and were followed by water resource use, project objective,

**Table 1.** Criteria and their assigned weights .

| | Criterion | | Weight |
|---|---|---|---|
| | ID | Name | |
| Project criteria | 1 | Water resource use | 3 |
| | 2.1 | Site sensitivity - seismicity | 4 |
| | 2.2 | Site sensitivity - hydrogeological instability | 1 |
| | 3 | Project objectives | 3 |
| | 4 | Catchment area | 3 |
| | 5 | Co-financing | 1 |
| | 6 | Project type | 4 |
| | 7 | Possibility subdivision in lots | 1 |
| | 8 | Project stage | 4 |
| Effectiveness criteria | 9 | Project effectiveness (ratio cost/ equivalent inhabitants) | 3 |
| | 10 | Territorial effectiveness | 2 |
| | 11 | District priority | 4 |
| TOTAL | 12 | | 33 |

catchment area, and project effectiveness, each with a weight of 3. For an easier understanding of the order of the criteria, a matrix was developed (Table 2).

The attributes assigned to each criterion and their scores are shown in Table 3. The normalization of the score is also reported because it was used to perform sensitivity analysis.

Although the Project stage was used to enter the selection, it was included in the MCA criteria. The criterion cannot affect the MCA result in any way since each alternative evaluated had the same score. However, it was decided to keep it in the process because the same method was adopted by the MIT, on another group of projects to be financed with the same Fund. Unlike Mipaaf, the MIT did not choose to focus only on executive projects. Therefore, it was necessary to maintain the criterion in order to make the results of the two selection processes comparable.

### *3.5 Calculation and sorting of alternatives and selection of the projects*

The summary indicator returned from the sum of the scores obtained from each project. It represented the effectiveness of the intervention proposal to meet the objective of the Fund. Based on the defined budget allocated by the Budget law, 10 projects were financed in the amount of almost 80 million euros (fig. 1 and table 4), all with a summary indicator of 22 to 26.

The 10 projects financed were in 7 Regions (Veneto, Lombardy, Emilia-Romagna, Tuscany, Abruzzo, Sicily, and Sardinia) and were implemented by 8 LAWMs. Figure 1 shows the location of the LAWM which received funding.

**Table 2.** Criteria order: Score matrix.

| Criteria | Site sensitivity - hydrogeological instability | Co-financing | Possibility subdivision in lots | Territorial effectiveness | Project effectiveness | Water resource use | Project objectives | Basin users | District priority | Site sensitivity - seismicity | Project type | Project stage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site sensitivity - hydrogeological instability | 1 | 1 | 1 | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Co-financing | 1 | 1 | 1 | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Possibility subdivision in lots | 1 | 1 | 1 | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Territorial effectiveness | 2 | 2 | 2 | 1 | 0.7 | 0.7 | 0.7 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 |
| Project effectiveness | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 1 | 0.8 | 0.8 | 0.8 | 0.8 |
| Water resource use | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0.8 | 0.8 | 0.8 | 0.8 |
| Project objectives | 3 | 3 | 3 | 4 | 1 | 1 | 1 | 1 | 0.8 | 0.8 | 0.8 | 0.8 |
| Basin users | 3 | 3 | 3 | 5 | 1 | 1 | 1 | 1 | 0.8 | 0.8 | 0.8 | 0.8 |
| District priority | 4 | 4 | 4 | 6 | 1.3 | 1.3 | 1.3 | 1.3 | 1 | 1 | 1 | 1 |
| Site sensitivity - seismicity | 4 | 4 | 4 | 7 | 1.3 | 1.3 | 1.3 | 1.3 | 1 | 1 | 1 | 1 |
| Project type | 4 | 4 | 4 | 8 | 1.3 | 1.3 | 1.3 | 1.3 | 1 | 1 | 1 | 1 |
| Project stage | 4 | 4 | 4 | 9 | 1.3 | 1.3 | 1.3 | 1.3 | 1 | 1 | 1 | 1 |

**Table 3.** Attributes and their scores. Row max normalization refers to normalization carried out before sensitivity analysis.

| Criterion | | Attribute | | Row max normalization |
|---|---|---|---|---|
| ID | Name | Name | Score | |
| 1 | Water resource use | Irrigation and household | 3 | 1.00 |
| | | Household | 2 | 0.67 |
| | | Irrigation | 1 | 0.33 |
| 2.1 | Site sensitivity - seismicity | Seismic zone 1 | 4 | 1.00 |
| | | Seismic zone 2 | 3 | 0.75 |
| | | Seismic zone 3 | 2 | 0.50 |
| | | Seismic zone 4 | 1 | 0.25 |
| 2.2 | Site sensitivity - hydrogeological instability | Yes | 1 | 1.00 |
| | | No | 0 | 0.00 |
| 3 | Project objectives | Completing of existing dams or unfinished dams | 3 | 1.00 |
| | | Recovery or extension of the reservoir' capacity | 2 | 0.70 |
| | | Improvement of the derivation' efficiency | 1 | 0.30 |
| 4 | Catchment area | EI > 500.000 | 3 | 1.00 |
| | | 300.000 ≤ EI ≤ 500.000 | 2 | 0.70 |
| | | EI < 300.000 | 1 | 0.30 |
| 5 | Co-financing | Yes | 1 | 1.00 |
| | | No | 0 | 0.00 |
| 6 | Project type | Securing | 4 | 1.00 |
| | | Extraordinary maintenance | 3 | 0.75 |
| | | Completion | 2 | 0.50 |
| | | New intervention | 1 | 0.25 |
| 7 | Possibility of subdivision in lots | Yes | 1 | 1.00 |
| | | No | 0 | 0.00 |
| 8 | Project stage | Executive project | 4 | 1.00 |
| | | Final authorizing project | 3 | 0.75 |
| | | Definitive technical project | 2 | 0.50 |
| | | Feasibility project | 0 | 0.25 |
| 9 | Project effectiveness | < 25€/EI | 3 | 1.00 |
| | | >=25 €/EI <50 €/EI | 2 | 0.70 |
| | | >=50€/EI | 1 | 0.30 |
| 10 | Territorial effectiveness | > 40% very sensitive danger *(Basilicata, Marche, Molise, Puglia, Sicily, and Sardinia)* | 2 | 1.00 |
| | | > 40% moderately sensitive danger *(Abruzzo, Campania, Emilia-Romagna, Lazio, Piedmont, Tuscany, Umbria, and Veneto)* | 1 | 0.50 |
| | | little sensitive *(other Regions)* | 0 | 0.00 |
| 11 | District priority | Strategic | 4 | 1.00 |
| | | Relevant | 3 | 0.75 |
| | | Important | 2 | 0.50 |
| | | Required | 1 | 0.25 |

Among the financed projects, 2 of them concerned the increase in storage capacity to improve the availability of water for agriculture; the remaining projects concerned improving the efficiency of the main irrigation supply networks in order to achieve better efficiency in water use and water saving in agriculture.

Under the same Plan, other projects were selected by the Ministry of Infrastructure using the same methodology for a total of 30 projects for about 250 million euros.

**Table 4.** List of scores awarded to selected projects for each criterion: evaluation matrix.

| Project | Criteria | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Position | Water resource use | Project objectives | Catchment area | Co-financing | Project type. | Possibility subdivision in lots | Project stage | Project effectiveness | Site sensitivity - seismicity | Site sensitivity - hydrogeological instability | Territorial effectiveness | District priority | summary Indicator |
| 1 | 3 | 1 | 3 | 0 | 4 | 1 | 4 | 3 | 2 | 1 | 1 | 3 | 26 |
| 2 | 3 | 2 | 1 | 0 | 4 | 1 | 4 | 3 | 1 | 1 | 1 | 3 | 24 |
| 3 | 3 | 2 | 1 | 0 | 4 | 0 | 4 | 3 | 1 | 1 | 1 | 3 | 23 |
| 4 | 1 | 1 | 3 | 0 | 3 | 1 | 4 | 3 | 1 | 0 | 2 | 4 | 23 |
| 5 | 1 | 1 | 3 | 0 | 3 | 1 | 4 | 3 | 1 | 0 | 2 | 4 | 23 |
| 6 | 3 | 1 | 1 | 0 | 3 | 1 | 4 | 1 | 3 | 1 | 1 | 4 | 23 |
| 7 | 1 | 1 | 3 | 0 | 3 | 1 | 4 | 3 | 2 | 0 | 1 | 3 | 22 |
| 8 | 3 | 1 | 3 | 0 | 3 | 1 | 4 | 3 | 1 | 0 | 0 | 3 | 22 |
| 9 | 1 | 1 | 1 | 0 | 4 | 0 | 4 | 3 | 3 | 0 | 1 | 4 | 22 |
| 10 | 1 | 1 | 1 | 0 | 3 | 1 | 4 | 1 | 3 | 1 | 2 | 4 | 22 |

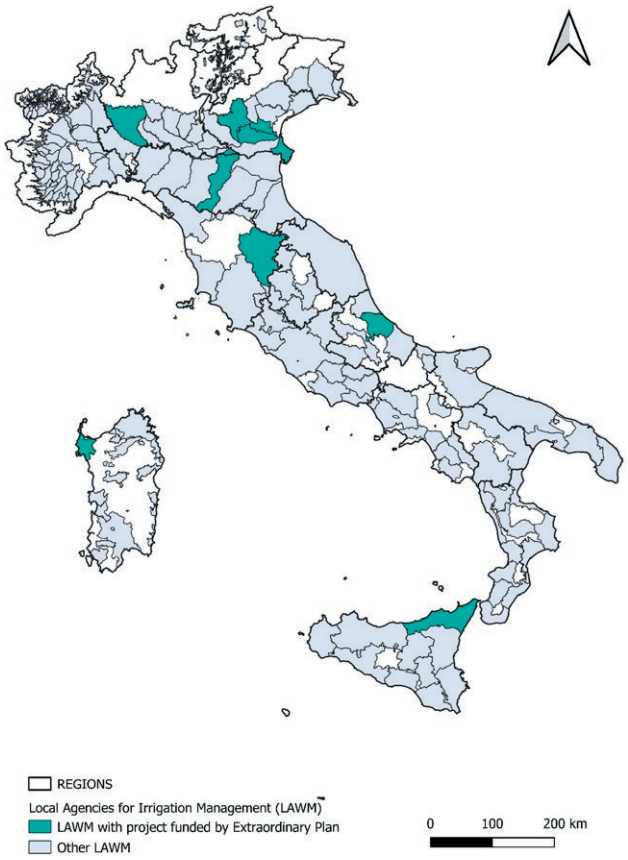


**Figure 1.** Maps of the Italian LAWMs. The blue polygons indicate the LAWMs that had their projects funded under the Extraordinary Plans from Mipaaf (*author's extrapolation of SIGRIAN data).*

*3.6 Sensitivity analysis*

Two other assumptions of weight allocation to the criteria were tested to apply sensitivity analyses within this study. Both were designed to follow the aims and rules of the Fund, but by making changes in the order of criteria However, the new assignations were made without a profound distortion of the priorities expressed by the Technical Committee.

In these new assignations, the correlation between the priorities expressed in the relevant law and the criteria that best represented them was considered.

The decision of the Technical Committee was amended to stress the weight of the criteria in two ways. Firstly, the importance was increased for criteria providing for the effects on the environment and community (e.g. number of people involved, mitigation of desertification, District priority, etc.), and the importance was decreased for criteria providing for the feasibility properties of the project (such as cost-efficiency ratio, possibility subdivision in lots, etc.) (R2). Then, the opposite point of view was applied (R3).

In R2, the most important criteria were established to be the District priority, the basin users, the seismicity of the site, the territorial effectiveness, and the project stage (weight 4), followed by the project objectives and project type (weight 3). They all described some aspect of the effect of the intervention, except for the project stage. The latter criterion had no effect on the final ranking of alternatives, but it could not be deleted or modified, as explained above (see paragraph 3.3). The lower

weights were for project properties, such as co-financing, the possibility of subdivision in lots (weight 0.5), water resource use (weight 1), project effectiveness, project type, and hydrogeological instability of the site (weight 2). The Technical Committee associated with the latter criterion the same weight as class 4 in seismic risk. In this way, seismic risk was emphasized more than hydrogeological risk, compared to the priorities expressed by the legislation, where priority was given to interventions in seismic area 1 or 2 and those affected by hydrogeological risk. In R2, the same trend was maintained but the presence of hydrogeological instability was associated with the same weight as the seismic risk class 3, shortening the distances between the two criteria.

On the contrary, in R3, the most important criteria were established as project effectiveness, project type, and project stage (weight 4), followed by water resource use, and the criteria on the effects (project objectives, basin users, site seismicity, District priority) (weight 3). The burden of co-financing and of the possibility of subdivision in lots were increased to 2. The lowest weights were placed on hydrogeological instability of the site and territorial effectiveness (weight 1).

Table 5 and Figure 2 summarize the weights adopted in the two tests in relation to those chosen by the Technical Committee (R1).

New summary indicators resulting for each alternative were obtained by multiplying the tested weights of the criteria by the normalized attributes score (see table 4). Then, as result of the aggregation with the scoring method, the alternatives were sorted according to R2 and R3. Table 6 shows the comparison of these alternative rankings for the first 10 projects. In both of the cases examined, two of the projects selected by the Technical Committee were not included in the top 10 ranking. Nevertheless, the comparison of the results for all 55 cases, by Spearman test (fig. 3), showed that there was a significant and strong correlation between the ranking performed based on R2 and R3 and the ranking performed on the basis of the assignment of the original weights (R1) (respectively 0.920 and 0.940, p-level<0,001, n=55). The results still showed a significant correlation when the Spearman test was calculated only on the top ten positions (respectively 0.641 and 0.681, p-level<0,05, n=10).

### *3.7 Discussions*

Looking at the adopted approach, the involvement of all stakeholders was a strength in the methodology. Firstly, it ensured competence in all the involved disciplinary areas. In particular, the involvement of the RBDAs was very important as they are key players in water management and protection. Secondly, it ensured a high level of objectivity in the definition of criteria and weights. Indeed, the multidisciplinary Technical Committee allowed for setting criteria, attributes, and scores, including the objectives and constraints imposed by the financial instrument, and shared weight distribution between decision-makers was achieved. Finally, this approach facilitated the acceptance of results obtained by the stakeholders embodied by the Regions.

The absence of traditional normalization and the assignment of a predefined score to attributes represented

**Table 5.** Weights of the criteria according to the two tests (*criteria mostly linked to the definitions given in the reference law), compared to those assigned by the Technical Committee.

| Main semantic area | Criteria | R1 | Weight in tested hypothesis | |
|---|---|---|---|---|
| | | | R2 | R3 |
| Project properties | *Water resource use | 3 | 2 | 3 |
| Project properties | Co-financing | 1 | 0.5 | 2 |
| Project properties | Possibility subdivision in lots | 1 | 0.5 | 2 |
| Project properties | *Project stage | 4 | 4 | 4 |
| Project properties | Project effectiveness | 3 | 2 | 4 |
| Project properties / effects | Project type | 4 | 3 | 4 |
| Effects / Project properties | *Project objectives | 3 | 3 | 3 |
| Effects | *Basin users | 3 | 4 | 3 |
| Effects | *Site sensitivity - seismicity | 4 | 4 | 3 |
| Effects | *Site sensitivity - hydrogeological instability | 1 | 2 | 1 |
| Effects | Territorial *effectiveness* | 2 | 4 | 1 |
| Effects | *District priority | 4 | 4 | 3 |
| Total weight | | 33 | 33 | 33 |

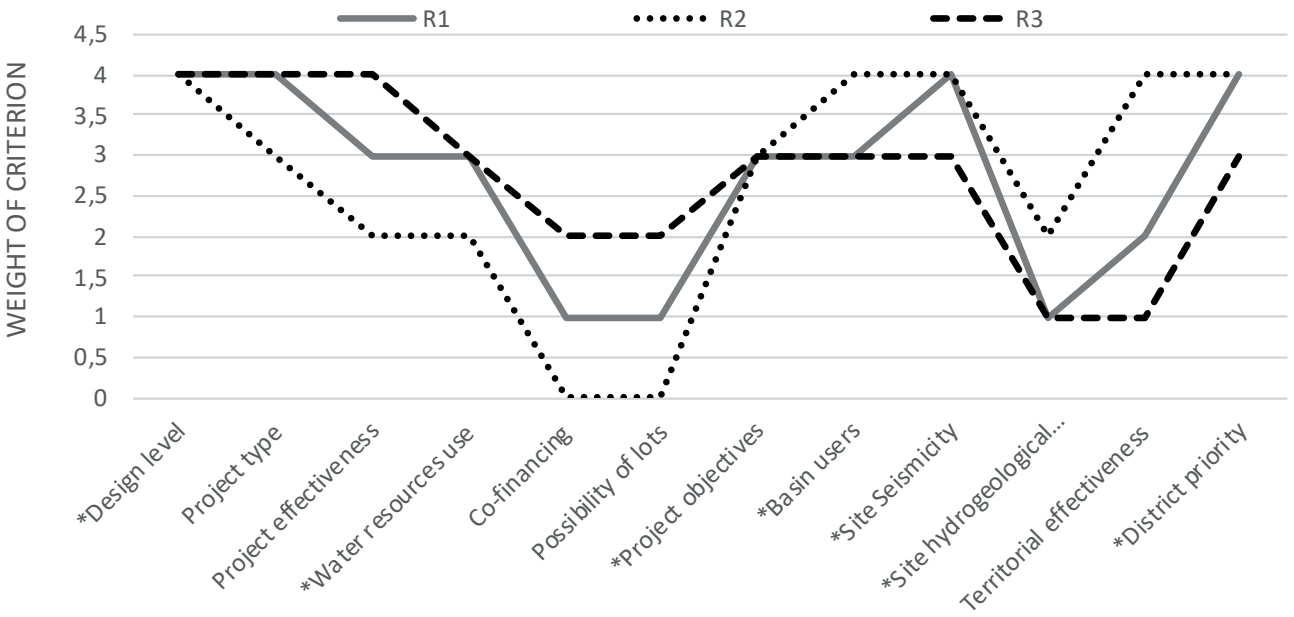


**Figure 2.** Graphic representation of the different weights of the criteria between the two tests and the assignment of the Technical Committee (*criteria mostly linked to the definitions reported in the reference law).

**Table 6.** The first 10 alternatives sorted by the summary indicator, obtained for R1 (the choices of the Technical Committee), R2, and R3 (the letters of the alphabet symbolize the alternatives, i.e. the projects).

| Ranking of the alternatives (first 10 positions) | | |
|---|---|---|
| by R1 adoption (technical committee) | by R2 adoption | by R3 adoption |
| A | A | A |
| B | D | B |
| C | E | H |
| D | L | D |
| E | B | E |
| F | F | C |
| G | C | G |
| H | Q | F |
| I | G | N |
| L | R | O |

a practical advantage: the method was easy for all parties involved to understand, making them even more confident in the results of the application. This was important for the self-assessment that stakeholders had to carry out when submitting their project, and for the RBDAs, which had to express their priority mainly based on the information included in the self-assessment.

In addition, two elements could make the methodology suitable for financing projects by means of a call for proposals. The first one consists of the direct assignment of the score to the attributes to facilitate the self-assessment. The second is the production of a definitive ranking of the proposals, without comparison with other test rankings, coming from sensitivity analysis (e.g. Skonieczny et al. 2005). In fact, sensitivity analysis is not suitable for funding guided by calls for proposals, because in these cases the scores of the attributes and/or weights of the criteria must necessarily be unequivocal, defined, and published *a priori*.

However, sensitivity analysis was applied to this study to verify the stability of the results when the weights of the criteria were changed. The results showed a good correlation between the ranking made on the two test hypotheses and that applied by the Technical Committee. The differences between the rankings were not significant. However, the small variations imposed on the weights of the test criteria during sensitivity analysis are worth noting. Surely this choice influenced the results of the sensitivity analysis, overestimating the quality of the results. On the other hand, if there were a profound variation in weight assignations, this would have resulted in choices that overturned the very strict and detailed rules and priorities of the Fund.

Overall, the study seemed to confirm that the allocation of the weights through a technical committee and the involvement of stakeholders achieved adequate solidity of the results. The analysis of the results also suggests that this solidity is higher when the regulation behind

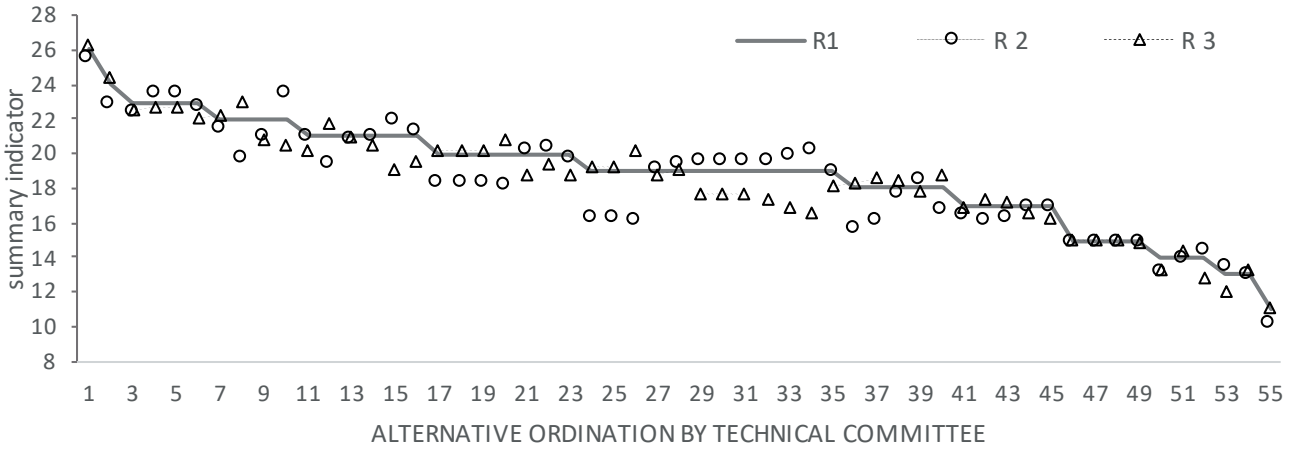


**Figure 3.** Graphic representation, for each alternative axis (X axis) of the summary indicator (Y axis) performed on the basis of R2 and R3 with those obtained from the assignment of the criteria of the Technical Committee.

the selection gives precise and detailed rules. This should reduce the discretion exercised by the Technical Committee.

## 4. MAIN CONCLUSIONS

Public infrastructure investments in water distribution networks are part of a broader framework of possible interventions (regulatory, risk management, investments, etc.) to cope with and adapt to climate change.

Recently, the European Green Deal Strategy also highlighted how climate change will continue to create significant stress in Europe despite mitigation efforts. Hence, the consideration of climate adaptation in public and private investments is an essential topic.

The MCA method proved to be a very useful tool for choosing between different investment alternatives. When it is well-designed, it allows for the inclusion of different quantitative and qualitative criteria that can be measured in a single evaluation process. This has also made it possible to weight these criteria according to the priorities assigned by decision makers.

However, the MCA procedure is articulated and complex, due to the need to develop an approach that represents the multiplicity of objectives. There is a risk that the results achieved will be strongly influenced by subjective choices made at some of the various stages. This can be a critical point. That is why sensitivity analysis should be applied. However, in some cases like those presented, a profound change in weight allocation for testing robustness is limited by the need to respect the priorities and constraints imposed by the related regulation. That is why decision maker and stakeholder involvement are even more necessary to achieve realistic and acceptable results.

During the application of the methodology described, certain strengths and weaknesses came to light. One of the main strengths was the participatory approach used to identify the decision-making network (Ministries and RBDAs) and stakeholders (Regions and LAWMs). The main weakness lies in the fact that the weights adopted can only be controlled ex-post, shifting the variation to weights to compare the results obtained.

The methodology applied has the advantage of being applicable in the future also in the case of funding based on calls for proposals, for which the scores of the attributes and/or the weights of the criteria must be defined and published *a priori*. The ex-post sensitivity analysis, carried out by modifying the weights with due regard for the priorities and limitations of the Fund, confirmed the solidity of the classification on the total number of cases. This solidity seems to be favoured precisely by the presence of accurate rules and priorities of the fund, which reduce the margin of discretion entrusted to the technical committee.

MCA is a useful informative support for policy decisions, but it is important to keep in mind that it is not an "automatic" method for land management.

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