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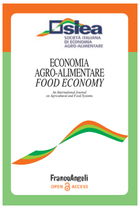

The contribution of national irrigation investment planning to sustainable water resource management in the Po River district

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Abstract

Safeguarding water resources has become a strategic need to maintain the viability of agricultural operations, which are significantly reliant on water accessibility. The urgency of this requirement is amplified by the manifest effects of climate change, necessitating the implementation of specific solutions to improve irrigation system efficiency and foster sustainable use of water resources.

This research seeks to conduct an ex-post analysis of irrigation investments in the Po River Basin District, Italy's most important agricultural area and one of the most irrigated in Europe, examining their sustainability by developing indicators that include technical, environmental, and social dimensions. The analysis examines interventions devised and executed by land reclamation and irrigation consortia, primarily targeting irrigation – including multipurpose reservoirs – as well as those directed towards environmental protection and the preservation of land and agricultural productivity amid instability.

Preliminary findings underscore the role of both current and prospective investments in enhancing the overall efficiency of the region. The research offers valuable insights for policymakers, affirming the critical importance of investments in irrigation infrastructure for enhancing the resilience and long-term sustainability of agriculture and the national water system.

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Introduction

To ensure the continuity of agricultural activities the conservation of water resources is now a strategic priority for every country (Hamam *et al.*, 2024). This need is further reinforced by the adverse effects of climate change, which makes it increasingly necessary to adopt measures aimed at improving the efficiency of irrigation systems (Et-taibi *et al.*, 2024). In this context, the strategic Green Deal project, through which the European Union aims to achieve climate neutrality by 2050, takes on particular importance (Boix-Fayos et *al.*, 2023).

In the ambitious plan for ecological reform, the protection of water resources plays a crucial role (Bieroza *et al.*, 2021). This is highlighted not only by the strategies of the Green Deal (Manzoni *et al.*, 2025), but also by the objectives of the Common Agricultural Policy 2023-2027 and, above all, the Water Framework Directive (WFD) (Bieroza *et al.*, 2021).

The latter has regulated European water bodies for over twenty years according to strict environmental sustainability standards through the implementation of River Basin Management Plans in the various Member States (Copetti and Erba, 2024). In this context, the new Water Resilience Strategy (Kumar *et al.*, 2020), recently released by the European Commission[1] to address the most urgent challenges in safeguarding the EU's water resources, is also particularly important (Srivastav *et al.*, 2021; Ricciardo Calderaro *et al.*, 2024).

As in other Member States, sustainable and efficient water management is also a priority in Italy (Colella *et al.*, 2021). Indeed, the Mediterranean area is a geographical context where the effects of drought and water stress (EEA, 2021) are having an increasingly significant impact on the economy, particularly on the agricultural sector (Vizinho *et al.*, 2021).

For this reason, the Ministry of Agriculture, Food Sovereignty, and Forestry is implementing a long-term investment strategy to modernize infrastructure and increase water efficiency (Vieira *et al.*, 2020; Jiang, 2023).

This study aims to analyze irrigation investments carried out in the Po River Basin District, assessing their sustainability from technical,

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2. The district fully encompasses the regions of Piedmont, Aosta Valley, Lombardy, and Emilia-Romagna, while it partially includes Liguria, Veneto, Tuscany, Marche, and the Autonomous Province of Trento. However, Tuscany and Liguria have no irrigated areas within the district, and in Marche, irrigated land accounts for less than 10% of the region's total area.

environmental, and social perspectives through the development of specific indicators related to the planned and implemented interventions in the area. In particular, the analysis focuses on projects promoted by land reclamation and irrigation consortia, primarily aimed at irrigation purposes, including the construction of multipurpose reservoirs, and at safeguarding agricultural land from hydrogeological risks.

The analysis focused on the Po River Basin District[2], the largest in Italy, covering an area of approximately 83,000 km² (Gharsallah *et al.*, 2024).

This territory was identified as the main recipient of funding, receiving about 34% of the total resources – equivalent to approximately €750 million, according to the CREA Yearbook 2023. Data on the funded investments and key indicators are stored in DANIA, the National Database of Investments for Irrigation and the Environment (Ferrigno *et al.*, 2022).

The investments considered in this research originate from three main, complementary public funding sources: a) the National Rural Development Program (NRDP) 2014-2020; b) the 2021 Agricultural Operational Plan (AOP), financed by the Development and Cohesion Fund (DCF); and c) the 2021 National Recovery and Resilience Plan (NRRP). The planning documents associated with these programs have been analyzed to identify their key objectives, which have been linked to the main targets of the Water Framework Directive (WFD), as outlined in the 2021-2027 River Basin Management Plan for the Po District (RBMP Po 2021-2027).

The research question addressed is as follows: "*In light of the water savings expected from the planned investments, to what extent and in what ways will they contribute to improving the sustainability of water resource management?*".

The article is structured as follows. The following section analyzes the planning documents associated with the interventions considered, to highlight the stated objectives regarding sustainability in water resource management and increased efficiency in their use for irrigation purposes. Based on this analysis, three indicators of the efficiency gains expected from the investments have been defined and are described in a section dedicated to the data and methodology used. This is followed by a section presenting the results of the analysis of data obtained from the DANIA database. Eventually, some considerations on the policy implications for water resource management are presented in the concluding section.

1. Promoting irrigation efficiency in the Po River Basin District

1.1. *Public funding sources*

a) National Rural Development Program (NRDP) 2014–2020

As part of the 2014-2020 CAP programming period, a National Rural Development Program (NRDP) was launched with the aim of supporting strategic interventions at the national level, including the modernization of irrigation networks. The program placed a particular emphasis on the sustainable and efficient use of water resources in agriculture, an increasingly important issue in the face of growing pressure on natural resources. Among the various measures included in the NRDP, Measure 4, dedicated to "Investments in physical assets" (ex-Article 17 of EU Regulation 1305/2013), plays a key role. Submeasure 4.3, which was allocated a total budget of €360 million, focuses on investments in infrastructure for the development and modernization of agriculture and forestry. This includes interventions related to access to agricultural and forest land, land consolidation, the improvement of energy and water infrastructure, and resource conservation. According to official documentation, the objective is to finance projects aimed at creating or upgrading irrigation infrastructure that can promote more efficient use of water. This includes initiatives to increase storage capacity, improve water management, and implement water-use monitoring systems. The measure, is intended for irrigation authorities, associated agricultural enterprises, and land improvement consortia, and provides for various investments in existing networks, aimed at:

- Upgrading existing irrigation distribution networks (23 projects);
- Improvement of water supply systems and/or installation of meters (13 projects);
- Functional completion of existing irrigation schemes and new irrigation infrastructure (7 projects);
- Investments in irrigation systems for land reclamation and irrigation, which may involve hydraulic works and regulation in the areas where the consortia operate (4 projects);
- Remote control systems (4 projects);
- Reuse of wastewater for irrigation (1 project);
- Restoration of basin efficiency and related supply and distribution works (1 project);
- Building of new reservoirs (1 project).

According to the NRDP, investments aimed at improving the efficiency of irrigated areas have covered a total surface of approximately 546,000 ha, corresponding to 18% of the total area equipped for irrigation. These interventions were designed to achieve an estimated water saving of around 235 million m^3.

b) Agricultural Operational Plan (AOP)

As a complement to the NRDP 2014-2020, the Agricultural Operational Plan (AOP) developed a strategy under Thematic Objectives 5-6[2] aimed at contrasting desertification, protecting ecosystems, and supporting the adaptation of agriculture to climate change, particularly in areas most at risk of flooding. Another key objective of the plan was to improve both the quality and quantity of water resources, with a focus on surface and groundwater bodies. To achieve these goals, Sub-Plan 2 was introduced, titled "Interventions in the field of irrigation infrastructure, hydraulic land reclamation, flood protection, storage basins, and related technical assistance and advisory programs". This sub-plan, backed by a budget of €295 million, aimed to consolidate and strengthen the national strategy for investments in irrigation infrastructure (p. 10). The document emphasizes the need for a strategic, national-level approach to ensure the effective and efficient use of the country's water resources. This includes ensuring that interventions are appropriately scaled and aligned with environmental sustainability, economic viability, and operational effectiveness. Such a strategy is increasingly urgent in a context marked by more frequent water crises and droughts resulting from ongoing climate change (pp. 10-11). The AOP also highlights several critical shortcomings in national water resource management. To address these issues, the planned actions aim to improve the quality of water bodies, both directly and indirectly, through a more rational and balanced use of available water (p. 14). Finally, the document details the eligible interventions (pp. 15), which include, for example:

- restoring the efficiency of water supply basins;
- building new of inter-company reservoirs managed by consortia and related adduction and distribution works;
- completion of existing irrigation schemes and new irrigation infrastructure;
- improvement of the supply systems and distribution networks of existing irrigation systems;
- upgrading of existing irrigation system distribution networks;
- investments in irrigation systems for land reclamation and irrigation;
- investments for energy production from mini-hydroelectric plants used for water lifting;
- investments in remote control systems;
- investments for the use of purified wastewater for irrigation;
- integrated strategic planning of national importance.

c) National Recovery and Resilience Plan (NRRP)

The National Recovery and Resilience Plan (NRRP) has also set clear objectives to improve the efficiency of water use. In particular, under Mission 2, titled "Green Revolution and Ecological Transition" €15.05 billion has been allocated to M2C4, dedicated to "Protection of the Territory and Water Resources" which includes several specific targets (p. 147):

- Strengthening the capacity to predict the effects of climate change through advanced and integrated monitoring and analysis systems;
- Preventing and combating the consequences of climate change on hydrogeological instability and the vulnerability of the territory;
- Safeguarding air quality and biodiversity in the territory through the protection of green areas, soil, and marine areas;
- Ensuring security of supply and sustainable and efficient management of water resources throughout the entire cycle.

About one-third of the funds allocated (4.38 billion) financed four types of investments:

- *Investment 4.1:* Investments in primary water infrastructure for water security;
- *Investment 4.2*: Reduction of losses in water distribution networks, including digitization and monitoring of networks;
- *Investment 4.3:* Investments in the resilience of the irrigation agrosystem for better water resource management;
- *Investment 4.4:* Investments in sewerage and wastewater treatment.

In light of the above, it can be noted that the sustainability objectives aimed at promoting a more efficient use of water resources, supported by the AOP, PNSR, and PNRR funds, are fully aligned with those established by the Water Framework Directive (Martinengo *et al.*, 2021), as well as with the ecological transition objectives outlined by the European Green Deal and the CAP 2023-2027. As highlighted in the Programme of Measures, which is the cornerstone of the Po River Basin Management Plan, these objectives, set out in Article 1 of the Water Framework Directive, are being actively pursued:

- To prevent further deterioration, protect and improve the status of aquatic ecosystems and terrestrial ecosystems and wetlands directly dependent on aquatic ecosystems in terms of water requirements;
- Facilitating sustainable water use based on the long-term protection of available water resources;
- To aim for enhanced protection and improvement of the aquatic environment, including through specific measures for the gradual reduction of discharges, emissions and losses of priority substances and the cessation or gradual elimination of discharges, emissions and losses of priority hazardous substances;

- Ensure the gradual reduction of groundwater pollution and prevent its increase;
- Contribute to mitigating the effects of floods and droughts.

1.2. *Key Types of Measures (KTMs) of the Po River Basin Management Plan*

To achieve these objectives, the Po River Basin Management Plan includes the implementation of several Key Type Measures (KTMs) (Figure 1), which are sets of coordinated actions designed to address common pressures affecting the status of water bodies within the district (Ruberto *et al.*, 2023). Among these, KTM.8 is particularly significant, as it focuses on "Measures to increase water efficiency for irrigation, industry, energy, and domestic use". This measure is broken down into a range of specific actions, all aimed at optimizing water use for irrigation purposes within the Po River Basin, as outlined in the Programme of Measures:

- *KTM08-P3-b039:* Mapping of irrigation efficiency and identification of targets for savings and/or efficiency improvements at different territorial scales (water body, irrigation scheme/consortium, sub-basin, district);
- *KTM08-P3-b041:* Implementation of plans to reduce withdrawals to achieve targets at different territorial levels to ensure the water saving objective defined by the District Water Balance Plan - Irrigation sector;
- *KTM08-P3-c121:* Structural actions to improve the irrigation system for the purpose of saving and using water resources efficiently;
- *KTM08-P3-b039:* Mapping of irrigation efficiency and identification of targets for savings and/or efficiency improvements at different territorial levels (water body, irrigation scheme/consortium, sub-basin, district);
- *KTM08-P3-b040:* Identification of efficiency levels, targets, and actions for water savings at the sub-basin and water body level – sectors other than irrigation;
- *KTM08-P3-b041:* Implementation of plans to reduce withdrawals to achieve targets at different territorial levels to ensure the water saving objective defined by the district-scale Water Balance Plan - Irrigation sector;
- *KTM08-P3-c121*: Structural actions to improve the irrigation system for the purpose of saving and using water resources efficiently.
- Furthermore, it is possible to note once again how the RBMP and the funds outlined above complement each other. In this regard, the Program of Measures identifies elements of synergy with the investments of the NRRP (p. 22, Table 4.1):

Figure 1 - Key Types of Measures (KTMs)

Codice Misura	Titolo Misura	DescrizioneIntervento	PNRR
KTM02-P2-b012	Realizzazione e utilizzo di tecnologie innovative per il trattamento degli effluenti zootecnici per promuovere interventi di economia circolare	Realizzazione di biodigestori per il trattamento degli effluenti zootecnici	M2C1 M2C2 (incentivo biometano)
KTM02-P2-b012	Realizzazione e utilizzo di tecnologie innovative per il trattamento degli effluenti zootecnici per promuovere interventi di economia circolare	Accordo di programma una gestione sostenibile degli effluenti zootecnici al fine di ottenere un miglioramento dello stato qualitativo dei corpi idrici riducendo il possibile impatto derivato dall'attività zootecnica.	M2C1 M2C2 (incentivo biometano)
KTM04-P1-a017	Realizzazione di interventi di bonifica dei siti contaminati e di messa in sicurezza	Bonifica dei siti orfani	M2C4 - Investimento 3.4
KTM06-P4-a022	Predisposizione dei Piani di gestione del demanio fluviale e lacustre e delle pertinenze idrauliche finalizzati alla ricostruzione di ambienti fluviali e lacustri diversificati e al recupero della biodiversità		M2C4
KTM06-P4-b027	Realizzazione di interventi integrati di mitigazione del rischio idrogeologico, di tutela e riqualificazione degli ecosistemi e della biodiversità (integrazione dir. Acque, Alluvioni, Habitat, Uccelli, ecc.)	Interventi di difesa idraulica sugli alvei che prevedano risezionamenti e miglioramenti sulle condizioni morfologiche dell'alveo e delle zone golenali e spondali, favorendo riduzione degli irrigidimenti, pluricursalità, riconnessione altimetrica	M2C4
KTM06-P4-b027	Realizzazione di interventi integrati di mitigazione del rischio idrogeologico, di tutela e riqualificazione degli ecosistemi e della biodiversità (integrazione dir. Acque, Alluvioni, Habitat, Uccelli, ecc.)	Interventi per la "Rinaturazione dell'area del Po"	M2C4 - Investimento 3.3
KTM08-P3-c121	Azioni strutturali per il miglioramento del sistema irriguo ai fini del risparmio e dell'uso efficiente della risorsa idrica	Investimenti nella resilienza dell'agrosistema irriguo per una migliore gestione delle risorse idriche	M2C4
KTM08-P3-c122	Azioni strutturali per assicurare il riequilibrio della disponibilità idrica a scala di area vasta	Investimenti in infrastrutture idriche primarie per la sicurezza dell'approvvigionamento idrico	M2C4
KTM14-P4-b088	Monitoraggio della situazione territoriale delle scale di risalita per la fauna ittica (analisi del funzionamento delle esistenti e censimento delle necessità di riconnessione e di deframmentazione)		M2C4
KTM26-P5-a108	Informazione, educazione e formazione sui contenuti e sull'attuazione del Piano	Formazione rivolta ai tecnici PA e degli Enti Locali su tipologia ed efficienza degli interventi integrati	M2C4

Source: River Basin Management Plan of the River Po District.

The Water Balance Plan of the Po RBMP also aims to protect water resources for future generations through criteria of solidarity and compliance with environmental standards, addressing the climate change currently underway. As can be seen in Annex 1.2 of Document "Update of the district characteristics", among the general objectives of the Water Balance Plan, Objective 3 "Water crisis and drought management" promotes "proactive management of water scarcity in drought conditions, in order to minimize its impact on the socio-economic and environmental system, also taking into account possible future climate change scenarios". This general objective is divided into three Specific Objectives (p. 7):

- Promote the implementation of a shared system for real-time monitoring of the water balance, drought forecasting, and early warning, based on best practices, appropriate technologies, and reasonable costs;

- Identify the actions necessary for proactive drought management at the district level, including defining critical parameters for classifying the current climate condition (indicators, climate variables, and thresholds);
- Define criteria and guidelines for the development/alignment of regional and/or district plans aimed at water conservation.

2. Materials and methods

The assessment of irrigation investment policies, their planning, and the selection of infrastructure has a significant and lasting impact on numerous stakeholders; for this reason, it was necessary to consider multiple objectives using a multi-criteria analysis (Zargham *et al.*, 2011). In general, identifying and evaluating viable project options is a fundamental step in finding the most satisfactory solution in terms of economic development opportunities, environmental impact and social impact.

Multi-Criteria Analysis (MCA) techniques are an effective approach to this end, as they are methodological tools that allow project alternatives to be compared based on multiple evaluation criteria.

In the simplest case, the choice between different alternatives can be guided by a single decision criterion. In economic evaluations, for instance, investments are ranked according to the balance between their cost and benefits (Mishan, 1988), as measured by the net present value (the discounted difference between benefits and costs) or the internal rate of return. However, in spatial planning and environmental assessments, it is rarely possible to rely on a single objective.

In the context of irrigation investments, for instance, the decision to build a new system or modernise an existing network cannot be based solely on economic factors. Other criteria must also be considered, such as:

- environmental sustainability (water savings, impact on ecosystems, water quality);
- social compatibility (benefits for agricultural communities, equity in the distribution of resources);
- climate resilience (the system's ability to adapt to changes in water availability);
- technical and economic efficiency of the intervention.

Multi-criteria analysis enables the integration of various aspects, combining quantitative criteria, such as costs, benefits, and irrigation volumes, with qualitative criteria, such as landscape impacts, environmental contraints and social acceptability. These are expressed in their respective units of measurement as well as through dimensionless indices based on expert assesment.

The main advantage of MCA over other economic techniques, such as cost-benefit analysis, is its methodological flexibility. It is possible to include heterogeneous criteria and weight them, accordingly, evaluating each element with the most appropriate assessment method.

Furthermore, environmental impact assessments – including those relating to large-scale irrigation projects – consider more than just the perspectives of technicians and researchers. It is now recognised that the decision-making process must also involve local communities and stakeholders, such as farmers, land reclamation consortia, administrations and citizens.

From this perspective, the analysis is multi-criteria and multi-decision, aiming to represent the different preferences, expectations and needs of those involved. This participatory approach helps make decisions more widely accepted, sustainable and long-lasting, which is essential for the success of any irrigation investment geared towards sustainability and efficient water resource management. In the latter case, the use of MCA lies in the need to treat water as a scarce resource and combine multiple criteria in management decisions rather than just one.

Multicriteria analysis has been designed and is widely applied as a decision tool in allocating limited resources among alternative interventions. In theory, every complex investment program should follow a coherent process where alternative options of investment are compared with reference to a set of goals to be pursued (economic, environmental, social), based on a set of quantitative indicators (Zargham and Szidarovszky, 2011). The expected result is a list of investments ordered to maximise the results valued against a multiple set of criteria. The decision procedure should include also a formal quantification of weights expressing how possible trade-offs among different goals have to be managed, according to the preferences of decision makers. A wide set of quantitative techniques (such as for example the *analytic hierarchy process*, cfr. Saaty & Vargas, 2012) can support the participatory processes where the relative importance of different goals is negotiated and weights decided.

In our analysis we adopt an ex-post, evaluation perspective of investment decision done. Projects have been already financed and partially implemented, according to a set of planning documents whose goals have been discussed in the previous section. We assume that the investment decisions have be done according to a multiple set of criteria to pursue different policy goals (Table 1).

We assume that each objective has been represented in the decision process by a quantitative indicator. Our aim is to provide evidence on the relative importance (weight) given to each of these indicators in the decision process. The contrast with stated goals, as expressed by planning documents, and the actual relative importance given to different goals will provide a first evidence on coherence of the planning process, useful to orient investment decision in the future.

Table 1 - Ex-post decision analysis for an overview of irrigation investments promoted by the Ministry of Agriculture

Purpose	**Objectives**	**Criteria**
Increase water efficiency in agriculture	Social	Safeguard agricultural businesses
	Environmental	Enable water savings and protect ecosystems
	Economic	Ensuring the country's food sovereignty and safeguarding food security in production

We have therefore extracted data from the DANIA database on 28 irrigation authorities in five regions, with 73 projects at various stages of funding:
- Planned for financing;
- Financed;
- Under construction;
- In operation.

The projects analyzed were divided according to the source of funding, beneficiary, and type of project:
- Law 145/2018;
- Law 160/2019;
- AOP 2019;
- Law 178/2020;
- AOP 2022;
- NRDP;
- NRRP.

The projects were selected from the DANIA database based on the completeness of the data relevant to the survey, about:
- Expected water savings;
- Area made more efficient by the intervention;
- Amount financed.

Based on the selected data, the following indicators were then calculated, reflecting the water efficiency objectives for irrigation outlined by the various funding programs from three different perspectives (criteria):

- *Amount financed per hectare made efficient (economic indicator – ECO1):* This indicator concerns the economic intensity of the investment per hectare of area made efficient; it can be considered an indicator of the "dimensional" efficiency of the planned interventions;
- *Cubic meters of water saved per euro invested (economic indicator – ECO2):* This indicator considers the efficiency of investment expenditure in terms of "cost-effectiveness", considering the capacity of each euro of investment to contribute to water savings; it can be considered an indicator of the "technical" efficiency of the planned investment in achieving water saving targets;
- *Cubic meters of water saved per hectare made more efficient (Environmental indicator - AMB1):* This is an indicator of the "environmental" efficiency of the intervention measured as the gain in efficiency in the use of water for irrigation per hectare of land subject to the planned investments.

For each intervention, the three indicators mentioned above were calculated, along with a normalized index that allows the distance between the different interventions to be analyzed, measured based on the indicators with a value ranging from 0 (worst case) to 1 (best case) according to the formula:

$$X_{i,j} = \frac{x_{i,j} - x_{j\ worst}}{x_{j\ best} - x_{j\ worst}}$$

Where $x_{i,j}$ is the value of the indicator j in the intervention i, while $x_{j\ best}$ and $x_{j\ worst}$ are the values of the indicator j in the most efficient and least efficient cases, respectively.

The average values of the indices and ranks obtained from the investments were grouped by source of funding and region and were weighted according to the cost of the investment in the case of dimensional efficiency (ECO1 index), the m^3 of water saved in the case of technical efficiency (ECO2), and the areas of intervention in the case of environmental efficiency (AMB1), according to the formula:

$$W_{j,r} = \frac{\sum_{i=1}^{n_r} X_{i,j} w_{i,j}}{\sum_{i=1}^{n_r} w_{i,j}}$$

Where:

- $W_{j,r}$ is the weighted average of the efficiency index j in the case of the source of funding/region r;

- $X_{i,j}$ is the efficiency index of the intervention *i*;
- $w_{i,j}$ is the weight assigned to the intervention *i* in the case of the index *j* (Euros invested, m^3 of water saved and ha of surface area transformed for dimensional, technical and environmental efficiency, respectively);
- n_r is the number of interventions included in the funding source/region *r*.

3. Results and discussions

Total investments relating to the 73 interventions considered in the Po River Basin District in the period 2018-2024 exceeded €666 million. About the equipped area, the investments involve approximately 419,000 hectares, while for water saving approximately 320 million m^3 have been calculated when the investments are fully operational. Combining the importance of assessing the sustainability of irrigation infrastructure investments and balancing the economic and social benefits of irrigation with the protection of the environment and natural resources, an analysis was carried out of how much the water efficiency of the area affected by these interventions would increase.

The following tables show the essential data for the 15 most efficient interventions, ranked according to the value of the indicators (ECO1, ECO2, and AMB1).

Amount financed per hectare of efficiency gained (ECO1)

Table 2 shows the investments based on the ECO1 indicator. This indicator is given by the ratio between the unit cost of the investment (€) and the area covered by the intervention (ha) and allows the economic intensity of the investment per hectare of surface area to be assessed.

In this case, the indicator is sorted in ascending order, indicating a preference for interventions involving lower expenditure per unit of area. Looking at the normalized index, the difference between the values of the best investments is minimal, demonstrating substantial homogeneity. It is important to note, however, that only 7.6% of the funds available for all sources of financing were allocated to the investments shown in the table. About size efficiency, the allocation of resources favored less efficient interventions: only 39.3% of resources were allocated to the 50% best interventions.

Table 2 - Interventions ranked according to the value attributed to the economic indicator (ECO1)

ID	Sources of funding	Region	Amount (€)	Area (ha)	Water saving (mc)	ECO1 Dimensional efficiency (€/ha)	Index
73	AOP 2022	Veneto	494.790	14.404	35.570.880	34,35	1,000
72	AOP 2022	Emilia-Romagna	499.590	13.434	303.293	37,19	1,000
71	AOP 2022	Emilia-Romagna	500.000	12.072	35.870	41,42	1,000
70	AOP 2022	Lombardia	484.421	11.566	3.945.981	41,88	1,000
69	AOP 2022	Veneto	483.970	8.480	890.400	57,07	1,000
68	AOP 2022	Emilia-Romagna	420.000	4.222	2.273.037	99,48	0,999
67	L. 145/2018	Lombardia	1.428.708	11.566	600.000	123,53	0,999
66	NRDP	Lombardia	5.547.177	37.000	39.810.000	149,92	0,999
65	L. 178/2020	Emilia-Romagna	2.709.821	13.622	2.202.548	198,93	0,998
64	AOP 2022	Emilia-Romagna	483.565	1.107	1.181.730	436,82	0,995
63	NRRP	Emilia-Romagna	2.700.000	5.470	2.640.000	493,60	0,995
62	L. 178/2020	Emilia-Romagna	8.706.145	17.413	1.889.473	499,98	0,995
61	L. 178/2020	Piemonte	9.609.688	13.994	625.845	686,70	0,992
60	NRDP	Lombardia	4.710.674	6.500	7.150.000	724,72	0,992
59	NRDP	Emilia-Romagna	11.788.043	14.700	2.283.070	801,91	0,991

Cubic meters of water saved per euro invested (ECO2)

Table 3 shows investments ranked according to the ECO2 indicator. This indicator is given by the ratio between m^3 of water saving and euros invested, a cost-effectiveness ratio that represents the technical efficiency of the interventions.

Table 3 - Interventions sorted according to the value assigned to the economic indicator (ECO2)

ID	Sources of funding	Region	Amount (€)	Area (ha)	Water saving (mc)	ECO2 Techno-economic efficiency (mc/€)	Index
73	AOP 2022	Veneto	494.790	14.404	35.570.880	71,9	1,000
70	AOP 2022	Lombardia	484.421	11.566	3.945.981	8,1	0,113
66	NRDP	Lombardia	5.547.177	37.000	39.810.000	7,2	0,100
68	AOP 2022	Emilia-Romagna	420.000	4.222	2.273.037	5,4	0,075
25	L. 178/2020	Piemonte	8.243.677	2.127	25.228.800	3,1	0,043
64	AOP 2022	Emilia-Romagna	483.565	1.107	1.181.730	2,4	0,034
69	AOP 2022	Veneto	483.970	8.480	890.400	1,8	0,026
52	AOP 2019	Lombardia	4.000.000	3.500	6.415.081	1,6	0,022
60	NRDP	Lombardia	4.710.674	6.500	7.150.000	1,5	0,021
53	NRRP	Veneto	7.200.943	6.357	10.582.488	1,5	0,020
13	NRDP	Veneto	5.500.000	550	8.000.000	1,5	0,020
16	NRDP	Lombardia	6.507.960	849	7.907.518	1,2	0,017
43	NRDP	Piemonte	5.925.684	3.258	6.259.153	1,1	0,015
39	NRRP	Veneto	7.500.000	3.646	7.543.197	1,0	0,014
63	NRRP	Emilia-Romagna	2.700.000	5.470	2.640.000	1,0	0,014

In this case, the indicator is sorted in descending order, as interventions that achieve greater water savings for the same expenditure are preferred. Looking at the normalized index, there is a significant gap in terms of technical efficiency within the group of most efficient interventions. In particular, the "best" investment in terms of cost-effectiveness is in a different order of magnitude in terms of water savings achieved. This outcome can be attributed to the investment's objective of modernizing the remote monitoring system of the entire irrigation district. As a result, it entails lower costs while delivering higher water savings than interventions centered on the rehabilitation and upgrading of irrigation infrastructure. In the case of technical efficiency, the overall allocation also favored less efficient interventions: the best 50% of all interventions considered were financed with 37.7% of resources.

Cubic meters of water saved per hectare improved (AMB1)

Table 4 shows the best investments based on the AMB1 indicator. This indicator is given by the ratio between m^3 of water saved and areas (ha) made more efficient and allows the technical and environmental efficiency gains in water use for irrigation generated by the investments to be assessed.

Table 4 - Interventions ranked according to the value assigned to the economic indicator (ECO2)

ID	Sources of funding	Region	Amount (€)	Area (ha)	Water saving (mc)	AMB1 Environmental efficiency (mc/ha)	Index
13	NRDP	Veneto	5.500.000	550	8.000.000	14.545	1,000
25	L. 178/2020	Piemonte	8.243.677	2.127	25.228.800	11.861	0,815
7	NRDP	Veneto	6.200.000	505	5.131.123	10.161	0,698
14	NRDP	Lombardia	5.225.032	527	4.908.436	9.314	0,640
16	NRDP	Lombardia	6.507.960	849	7.907.518	9.314	0,640
9	NRDP	Veneto	8.300.000	760	5.515.776	7.258	0,499
10	NRDP	Lombardia	5.421.550	514	2.837.773	5.521	0,379
5	NRDP	Piemonte	20.000.000	1.150	5.266.000	4.579	0,315
4	AOP 2019	Piemonte	7.325.000	220	970.000	4.409	0,303
8	L. 145/2018	Piemonte	3.330.000	290	1.200.000	4.138	0,284
2	L. 160/2019	Lombardia	7.600.000	166	680.000	4.096	0,281
17	NRRP	Emilia-Romagna	14.250.000	2.090	8.503.905	4.069	0,280
1	L. 145/2018	Valle D'Aosta	15.000.000	177	612.800	3.462	0,238
26	NRDP	Veneto	9.816.637	2.703	9.072.000	3.356	0,231
15	NRDP	Lombardia	4.279.802	475	1.500.000	3.158	0,217

Source: Author's elaboration.

In this case too, the indicator is ranked in descending order, as greater water savings, for the same surface area, are desirable. Looking at the normalized index, the dispersion of values in the 15 best investments is quite significant and greater than in the previous indicators, indicating that the different nature of the interventions and the different conditions in which they are carried out can lead to quite diverse results in terms of efficiency in water use for irrigation. In the case of the environmental efficiency indicator, the overall allocation of funds is better than the previous criteria: the best 50% of all investments were financed with about half of the resources (48.3%).

Tables 5 and 6 compare the sources of funding and the regions based on the average ranking obtained by the respective investments in relation to the various indicators.

Table 5 - Evaluation of funding sources based on the average ranking of the indicators considered

Source of funding	**Amount**		**Dimensional efficiency (€/ha)**		**Techno-economic efficiency (€/m³)**		**Environmental efficiency (m³/ha)**	
	M€	**%**	**Average index**	**Average rank**	**Average index**	**Average rank**	**Average index**	**Average rank**
AOP 2019	43,1	6,5	0,876	42	0,012	28	0,037	49
AOP 2022	3,4	0,5	0,999	4	0,820	2	0,046	53
L. 145/2018	33,8	5,1	0,526	55	0,004	40	0,020	59
L. 160/2019	26,0	3,9	0,828	40	0,006	28	0,042	47
L. 178/2020	105,2	15,8	0,941	35	0,026	20	0,038	57
NRRP	257,5	38,6	0,956	41	0,008	29	0,048	43
NRDP	197,3	29,6	0,928	46	0,039	18	0,082	38
Total	666,3	100,0	0,914	42	0,135	20	0,052	47

Source: Author's elaboration.

Regarding the first indicator, the best average ranking is associated with AOP 2022 funding, which otherwise has one of the worst values for the environmental efficiency indicator. On the other hand, there is an opposite trend for interventions financed by Law 145/2018, which are the most efficient in terms of water saving (ECO2) but have a worse rating for the size efficiency indicator (ECO1) at the highest value.

More generally, it should be noted that resources were allocated with a preference for measures that were more efficient in terms of savings per unit of area (ECO1) than in terms of technical (ECO2) and environmental (AMB1) efficiency. This result probably reflects the existence of a trade-off between the different efficiency criteria.

If the different sources of funding represent different "models" of resource allocation, and assigning equal importance to the three evaluation criteria, the AOP 2022 program dominates the other funds. It is in fact the fund that, on average, places its interventions at the shortest distance from an ideal irrigation investment hypothetically capable of obtaining the best score across all indicators. This distance can be measured as the difference between the overall score that the "ideal" investment would obtain and the sum of the average normalized scores obtained by each funding line. In the case of the investments considered, the distance varies from 2.450 in the case of investments financed under Law 145/2018 to 1.134 in the case of the AOP 2022 program. Obviously, this result strictly depends on the assumption that equal importance is assigned to the three evaluation criteria and could change if the indicators were "weighted" differently.

Table 6 - Evaluation of regions based on the average ranking of the indicators considered

Region	**Amount**		**Dimensional efficiency (€/ha)**		**Techno-economic efficiency (€/m³)**		**Environmental efficiency (m³/ha)**	
	M€	**%**	**Average index**	**Average rank**	**Average index**	**Average rank**	**Average index**	**Average rank**
Emilia-Romagna	297,7	44,7	0,950	40	0,008	36	0,023	56
Lombardia	126,8	19,0	0,926	42	0,051	15	0,064	38
Piemonte	154,4	23,2	0,930	42	0,020	23	0,066	47
Valle D'Aosta	22,3	3,3	0,153	72	0,001	70	0,129	36
Veneto	65,0	9,8	0,944	41	0,397	10	0,114	34
Total	666,3	100,0	0,914	42	0,135	20	0,052	47

Source: Author's elaboration.

Moving on to a comparison between regional areas, Emilia-Romagna, which is the region in which the largest share of funds was invested (44.7%), is the most efficient in terms of the first indicator, even though its projects are ranked higher on average than the average for technical efficiency. The Veneto region achieves the best average score for indicators ECO2 and AMB1 in relation to the first and third indicators, ECO1 and AMB1, presenting the resource allocation "model" closest to the "ideal" one[3]. Finally, Valle d'Aosta is the region where environmental efficiency has been given the highest priority, favoring interventions that achieve greater water savings per unit of surface area.

Conclusions

The Po River basin is one of the most important agricultural areas in Italy and Europe. It is characterised by high demand for irrigation, a variety of irrigation systems (surface, pressure and sub-irrigation) and an increasing vulnerability to the effects of climate change, such as drought, reduced flow rates and rising temperatures. In this context, irrigation measures must address production needs and the principles of water conservation, the protection of river and agricultural ecosystems, and climate change adaptation. Irrigation actions have dual value: they increase the agricultural system's resilience and promote the rational use of water resources, which is essential for ensuring the sector's future sustainability.

The decision to focus the analysis on the Po District is based on the understanding that modernising the area's irrigation infrastructure is crucial to its productivity. In recent years, the area has experienced severe droughts that have had a significant impact on agriculture. Therefore, investments must make the system more resilient by increasing storage capacity and adopting digital solutions for efficient water management. These investments represent an effort to modernise the extensive and historic network of irrigation canals, which are often obsolete and inefficient. This modernisation is integrated into an approach to managing water resources that includes planning the water balance, monitoring flows and withdrawals, and proactively managing droughts and water surpluses.

The ex-post multi-criteria analysis results provided in this paper is useful for assessing infrastructure investment sustainability. According to planning documents we evaluated the funded investments using criteria going beyond traditional economic parameters, revealing impacts that would otherwise be overlooked or underestimated. Recognising the critical importance of spending on irrigation investments to the future sustainability of agriculture and the national water system is essential, especially in the context of growing challenges related to climate change and resource efficiency. The adopted multi-criteria analysis provides a first evaluation of the investment performance, as the results depend on the sample and normalisation procedures used rather than external benchmarks. This limitation has been explicitly acknowledged, clarifying that the results should be interpreted as comparative judgements of coherence in investment decisions rather than definitive evidence of their sustainability.

Adopting a multi-indicator assessment supplemented by a standardisation system addresses several issues: it accounts for the territorial variability of irrigation systems in the Po basin (including gravity, pressure, micro-irrigation, and sub-irrigation systems); it supports governance and integrated planning; it measures environmental and climate impacts; and it demonstrates the value of public interventions using objective data, thereby fostering trust and accountability among local communities and stakeholders.

The initial results suggest that the investments made or planned are improving the area's efficiency in several ways. Particular attention is paid to investments that reflect "dimensional efficiency", i.e. the extension of the efficient irrigated area, even if this comes at the expense of other parameters, such as water savings per euro invested or impact per unit of area. The study allows the ex-post verification of whether choices are consistent with the set objectives, and whether the highlighted compromises are due to technical reasons or conscious planning choices.

The Po District's experience represents a model that can be replicated in other Italian irrigation areas. The method based on standardised indicators enables a more in-depth, comparative and integrated assessment of investments. This helps to optimise public resources, improve the targeting of strategic priorities, strengthen the resilience of agricultural systems, and promote sustainable water use. In a context of increasing water scarcity and stricter environmental regulations, this approach is essential for ensuring modern, efficient and sustainable irrigation in the long term.

Conflicts of interest

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