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Article

A Synthetic Indicator for Sustainability Standards of Water Resources in Agriculture

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Abstract: The aim of this work is to evaluate the sustainability of water management for agriculture in a specific territory through the creation of a synthetic index resulting from the aggregation of multiple indices (environmental, economic, and social). The resulting synthetic index can be used to set sustainability standards and to guide the choices mandated by the Common Agricultural Policy 2023–2027. In this work we intend to show how the Multiple Criteria Decision Analysis (MCDA) method facilitates a complex process such as establishing a degree of sustainability in a certain area and, therefore, provides support to national or regional policies and communities. The integration of MCDA and GIS increases the efficiency of the support activity. A case study is presented evaluating the level of sustainability in the Irrigation and Reclamation Consortium of Piacenza and Emilia Centrale, in the Emilia Romagna region.

Keywords: water management; sustainability; sustainability indicators; Common Agricultural Policy; MCDA

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1. Introduction

In recent decades the agricultural sector has faced important challenges, such as increasingly extended periods of drought, off-season extreme cold events, and difficulties in responding effectively to the global need for food because of climate change and the continuing population growth. Population growth implies the need to increase production and/or make production more efficient, and it involves greater pressure on natural resources. Therefore, the challenge for the agricultural sector is to increase production in a sustainable way [1]. With regard to the agricultural sector, the term "sustainability" refers to its ability to contribute in the long term to the general well-being of people by producing sufficient food, other non-food goods, and services in an economically efficient and profitable way, socially responsible and respectful of the environment [2]. The creation of a sustainable food system is one of the objectives of the European Green Deal, which identifies the Common Agricultural Policy (CAP) and the Common Fisheries Policy as key support instruments for achieving this objective. As a matter of fact, the tools that encourage sustainable agriculture management (e.g., the eco-scheme) have been strengthened in the CAP 2023–2027 proposal. The CAP is, in fact, increasingly oriented toward the protection of environmental resources, while maintaining the general objective of supporting farmers' incomes and keeping workers in rural and agricultural areas. This is in line with the principles of sustainable development, which require an integrated approach to the environmental, social, and economic aspects [3].

A sustainable management is particularly relevant to water resources for agriculture as the world's supply of clean and fresh water is steadily decreasing and extreme events (drought, floods) are becoming more frequent. Indeed, sustainable management of water (quantitative and qualitative) is also one of the Sustainable Development Goals of Agenda 2030 and is encouraged by the CAP. Specific goals of Agenda 2030 are improving water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, increasing water-use efficiency across all sectors, ensuring sustainable withdrawals and supplies of freshwater to address water scarcity, and substantially reducing the number of people suffering from water scarcity. To achieve these goals, it is necessary to reduce any activity's water footprint, so to decrease the direct consumption of any economic business, in both production and non-production processes (e.g., administrative) (Water Footprint Network).

However, to implement corrective action, it is necessary to identify which aspects of the production process adversely affect sustainability. To define whether a practice is sustainable or not, indices and attributes that quantify the level of sustainability are required. These indices must be specific to the analyzed production process and relative production area. "Indicators and composite indicators are increasingly recognized as a useful tool for policy making and public communication in conveying information on countries' performance in fields such as environment, economy, society, or technological development" [4]. There are several sustainability assessment methodologies. Ness et al. (2007) [5] developed a holistic framework for a sustainability assessment tool that includes (1) indicators and indices that are classified into non-integrated and integrated; (2) product-related assessment tools; and (3) integrated assessment. Integrated assessment methodologies are based on systems analysis approaches and integrate aspects of nature and society. Multiple Criteria Decision Analysis (MCDA) belongs to this category and responds to the aim of this work, which is to evaluate the sustainability of water management in a specific territory at local scale, i.e., the consortium, through the creation of a synthetic index from the aggregation of multiple indices (environmental, economic, and social). The resulting synthetic index can be used to set sustainability standards and to guide the choices required by the Common Agricultural Policy 2023–2027.

Our case study focuses on sustainability at the consortium level, and the selected indicators include elements that impact on the socioeconomic and environmental system of the territory under examination, going beyond the mere technical and economic efficiency of the consortia. With this approach it is possible to integrate technical problems related to the efficiency of water use and territorial problems, in order to integrate the positive and negative impacts related to the use of water in agriculture relating to all dimensions of sustainability.

The paper is organized as follows:

Section 3 presents the MCDA, explaining the underlying principles, the difference between it and the single criterion analysis, and the area of application. It also describes the integration of MCDA and the Geographic Information System (GIS) and the resulting benefits.

Section 4 is dedicated to data and methods and presents the area under study, the indicators identified, and the methodological procedure used.

Section 5 reports the results of the analysis and is accompanied by maps and graphs that facilitate the understanding of the results.

Sections 6 and 7 are the discussion and conclusion that explain the area of application of this work, its limits, and potentials.

In Section 7 other considerations of the results are made. In addition, a series of proposals are made on how to extend the study in the future and where some areas of application can be useful.

2. Background

Over the years, various studies have been conducted to evaluate sustainability through MCDA. Shmelev and Rodríguez-Labajos (2009) [6] assessed the sustainability of Austria with MCDA over the long term from 1960 to 2003; medium term, 1970–1995; and short term, 1995–2003. Deshpande et al. (2020) [7] assessed the environmental, economic, and social impacts of landfilling, incinerating, and recycling of waste fishing gears in Norway, using MCDA to rank the end-of-life (EOL) alternatives through their ability to sustainably manage the waste plastics from fishing gears in Norway. Haase et al. (2020) [8] used MCDA to conduct a comparative sustainability assessment of three renewable and fossil fuel production routes, i.e., gasoline from straw or wood, and conventional gasoline. In [9], Vivas et al. (2019) applied the model to assess the sustainability of a Brazilian oil and gas company, combining MCDA with statistical analysis.

MCDA has been used also to compare the sustainability of territorial units. Liu (2007) [10] assessed the environmental sustainability of 146 countries, considering air quality, water quality, water quantity, land use and natural resource, and biodiversity by combining MCDA and the Fuzzy logit. Some works for the sustainability assessment have been conducted at the municipal level. Ferrarini et al. (2001) [11] estimated the sustainability level of 45 municipalities in the Reggio Emilia Province (Emilia Romagna, Italy) through 25 environmental, social, and economic indicators. Boggia and Cortina [12] ranked 92 municipalities of the Umbria region (Italy) according to degrees of sustainability to offer the institutions financing information through the Regional Operative Plan and the Social European Fund. The municipal scale was chosen by the authors in accordance with the EU Sustainable Development Renewed Strategy (EU Council, 10917/06), which underlines the important role of local and regional levels in delivering sustainable development and building up social capital.

Furthermore, Zema et al. (2020) [13] analyzed the performance of Water User Associations (the irrigation consortia) regarding an increase in service sustainability in the Calabria region through benchmarking techniques. The study applied Permutational Multivariate Analysis of Variance (PERMANOVA), Multidimensional Scale Models (MDSs), and Distance-Based Linear Models (DISTLMs) as benchmarking techniques to evaluate the technical and financial performances of 10 Water User Associations (WUAs). The authors demonstrated that higher usage of the irrigation infrastructure allows an increase in the irrigated areas thanks to the water price and the size of the personnel staff decrease. Furthermore, they demonstrated that the self-sufficiency of the WUAs depends more on the size of the personnel staff, the maintenance, organization, and management costs, than on the dues fees and more limits on water prices. In this case only technical and financial sustainabilities were assessed; therefore, it differed from our work, which also considered the sustainability of the consortia from an environmental point of view.

3. The Issue of Multi-Dimensions of Sustainability

3.1. The Multiple Criteria Decision Analysis (MCDA)

The evaluation of sustainability is implemented through different methodologies and logical paths. One of the greatest challenges for data analysis is to summarize in a single value the social, economic, and environmental aspects that represent the vertices of the so-called sustainability triangle. According to Herath and Prato (2017) [14], MCDA is considered one of the main tools for solving this kind of problem, because it enables analysts to integrate the environmental, social, and economic objectives and to take into account the preferences of decision makers and stakeholders. Multiple Criteria Decision Analyses (MCDAs) are generally defined as "a decision support and a mathematical tool that allows you to compare different alternatives or scenarios depending on some criteria, often in conflict with each other, in order to guide the decision-maker towards one thoughtful choice" [15]. "A Multi-Criteria Analysis differs from a single criterion analysis in that it tends to yield explicit a family of criteria, which will serve as an intelligible, acceptable and exhaustive communication tool, to allow conception, justification and the transformation of preferences in a decision-making process" [15].

MCDA is a generic term to describe a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter [16]. Different alternatives or options become an MCDA problem when they can be judged or evaluated by a certain number of criteria that may conflict with each other. The alternatives are intended as the possibilities one must choose from [17]. The criteria are defined as a sort of quantitative or qualitative standard by which one particular alternative or option can be judged to be more desirable than another [16,18]. MCDA is currently applied in various areas within the framework of the management of natural resources in agriculture, including environmental management, energy policy analysis, farm and forest management, food security and nutrition, protection of natural areas, ecosystem services, soil and water management [17,19]. Basically, MCDA has intrinsic features that make it appealing and practically useful. Belton and Stewart (2002) [16] highlighted these features as follows:

- MCDA seeks to take explicit account of multiple conflicting criteria in aiding the decision making;
- The MCDA process helps to structure the problem;
- The MCDA methods used provide a focus and a language for discussion;
- MCDA helps decision makers to learn about the problem situation and their own judgments, and, thus, to guide them in identifying a preferred alternative or option through suitable information and an extensive discussion;
- MCDA serves to complement and to challenge intuition, acting as a sounding board against which ideas can be tested; it does not seek to replace intuitive judgment or experience;
- The MCDA process leads to better considered, justifiable, and explainable decisions and the analysis provides an audit trail for a decision;
- The most useful MCDA approaches are conceptually simple and transparent;
- The previous point notwithstanding, non-trivial skills are necessary to make effective use of such approaches in a potentially complex environment.

3.2. Integration of GIS and MCDA (MC-SDSS)

MCDA represents an important tool in environmental and territorial assessment. The traditional approach to MCDA finds a limit in the impossibility of effectively managing the geographical dimension that some natural, social, and economic phenomena assume. This characteristic is typical of geographic information systems (GISs). When the object treated is no longer the single set of data but a full scenario, the disciplinary sphere passes from that of geographic information systems to that of decision support systems (DSSs). The combination of multi-criteria techniques and geographic information systems expands the possibilities of evaluation and modeling of territorial phenomena.

Multicriteria Spatial Decision Support Systems (MC-SDSSs) is a category of SDSS based on the concept of integrating the Geographic Information System (GIS) and Multiple Criteria Decision Analysis (MCDA) [20]. The key motivation for integrating GIS and MCDA arises from the need to make the GIS capabilities more effective for decision making and planning [21,22]. Indeed, GIS technology is not well-suited for acquiring, storing, processing, analyzing, and visualizing data and information critical for decision-making processes such as value judgments, preferences, priorities, opinions, and attitudes [20,23]. Therefore, a way to deal with this issue is to integrate MCDA methods into the suite of GIS operations [20]. More specifically, GIS-MCDA can be defined as a procedure that transforms and combines geographic data (i.e., input maps) and the decision makers' or stakeholders' preferences into a decision map (i.e., output) [20]. Thus, this procedure requires the use of geographical data, the preferences, and the integration of the data and preferences according to a specified decision rule (i.e., combination) [20,23,24]. Consequently, GIS-MCDA integration involves the evaluation of the geographic decision alternatives according to the criteria values and the above preferences.

4. Data and Methods

In this paper, the objective is to evaluate the general sustainability of a territory, with particular attention paid to water resources for agricultural purposes and everything that could in some way compromise its quality or proper management.

To evaluate the sustainability level of the agricultural water management of a given territory, several economic, social, and environmental indicators were taken into account. The main data sources utilized for the analysis were SIGRIAN (National Information System for Water Resources Management in Agriculture) for the socio-environmental data related to water resources and IT-FADN for the economic data of irrigated agriculture. SIGRIAN contains information on water use in agriculture, such as crops and related irrigation volumes; irrigation volume withdrawn, used and returned; climatic characteristics; and consequently useful data for the population of the quantitative pressure indicators on water bodies [25]. Furthermore, it contains information for the population of ecological indicators, such as the presence of irrigation ditches with natural features. IT-FADN provides much information on the farm's physical and structural, economic, financial and asset data. To identify the aggregate indicator of sustainability, Multiple Criteria Decision Analysis (MCDA) was adopted, following the methodological framework developed by Boggia and Cortina (2009) [12]. This methodology aimed at providing information on the ability of the alternatives to simultaneously achieve the objectives represented by the indicators used in the analysis. The multi-criteria analysis was based on the construction of a matrix in which the values of each unit observed (territories) with respect to each individual indicator were represented. A weight system was also required, which provided information on the importance attached to the various indicators. The weight system was constructed through a focus group, during which, through the application of the methodology called Analytic Hierarchy Process (AHP) developed in the 1970s by Saaty, a priority scale was defined, or rather a hierarchy among the abovementioned indicators. The matrix of the pairwise comparisons gave rise to the vector of weights that, through a mathematical elaboration, were finally transformed into numbers whose sum must be 1 (or 100, depending on the scale used). AHP is based on pairwise comparisons of objectives and alternatives, from which the alternatives are ranked according to relative importance. With pairwise comparisons, the decision maker considers only two objectives at a time and the process of weighting objectives is thus facilitated [26]. The data aggregation took place through the algorithm called TOPSIS, based on the weights of the related indicators.

The areas under study coincided with the territories administered by the reclamation consortia of Piacenza and Emilia Centrale and were compared with the average values that summarized the general situation for the Emilia Romagna region (Figure 1). The chosen study area, coinciding with the territories administered by the consortia, allowed greater efficiency in guiding policies, as the current trend is to reward the work of the consortia and certify through the creation of sustainability marks aimed at the consortia themselves.

Furthermore, we must not forget the important work carried out by the consortia for the execution of the hydraulic reclamation works, the maintenance of the waterways, as well as the execution of hydraulic works and the protection of the territory in general, in addition to the distribution of irrigation resources for agriculture. Although the planning of water management takes place at the River Basin District level, the consortia, as intermediaries that deliver to users and subjects in charge of territorial protection, represent valid units for evaluating performance. The choice of the territorial area was also conditioned by the availability of detailed statistical data. In fact, many aggregated data at consortium level are available in the SIGRIAN database.

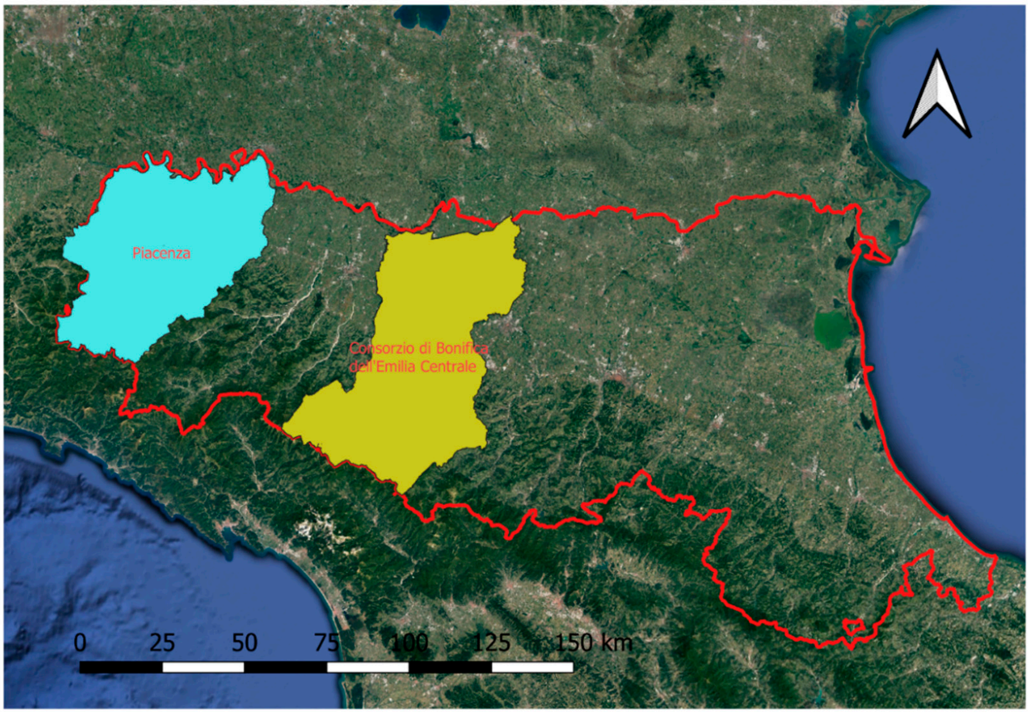

Figure 1. The image highlights the Emilia Romagna region (red border), the Piacenza consortium (blue) and that of Emilia Centrale (yellow).

4.1. The Choice of Indicators

For each area, common indicators were identified and compared, which were then elaborated through MCDA supported by the Geographic Information System.

The need to carry out the assessments taking the consortium as a territorial basis has, therefore, limited the choice to measurable parameters on a smaller scale. The indicators are of various kinds and were chosen in such a way as to embrace the various aspects of sustainability (environmental, social, and economic) under different aspects, trying to capture both company and consortium realities, and aspects related to the intrinsic qualities of the territory.

Environmental sustainability includes indicators significantly influenced by the management actions of irrigation consortia, e.g., "Quantity of irrigation water consumed in the plant production phase", "Energy consumption for water lifting by the region or the consortium", "Degree of efficiency of irrigation systems", etc., and others that cannot be influenced by the consortium management policies unless minimally and over a very long time, e.g., "Soil organic matter content".

With regards to the social sustainability indicators, we considered those regarding the landscape value of the territory and the investments made to improve irrigation infrastructures. The choice of landscape indicators was based on the impact of the landscape aspects of traditional irrigated agro-ecosystems on the well-being of the community. The landscape value belongs to the class of cultural ecosystem services codified by international classifications, such as CICES and TEEB [27,28]. Several studies have been conducted to estimate the Willingness to Pay for irrigated agricultural landscape [29–31]. In our work we considered the presence of uncoated irrigation canals, which, although they have a low degree of efficiency compared to other water transport systems, offer environmental (such as recharging aquifers) and landscape benefits [32]. Furthermore, the presence of vegetation along the banks was considered, which improves the quality of both the water and the landscape. The irrigation canals characterized by high naturalness benefit the landscape and are often used as destinations for recreational activities. The indicator was chosen for its clear definition and ease of replication; however, to quantify the landscape aspects related to irrigation, it would be necessary to carry out a mapping that enhances the landscape elements according to their historical–cultural value and the actual frequentation by the community for recreational activities.

Economic sustainability, on the other hand, refers both to corporate realities with indicators such as "Net Labor Productivity", "Incidence of public aid" and to territorial realities with indicators referring to the entire area within the consortium.

Table 1 shows a view of the indicators used, divided by category.

Table 1. The table shows the indicators identified, divided into environmental, social, and economic categories, the source of the data and the reference year.

	Indicator	Source	Year
Enviromental	Soil organic substance content	EMILIA ROMAGNA REGION MAP	2010–2015
	No. of stations monitored in eutrophic state	SINTAI—Directive 91/676/CEE—Nitrates	2012–2015
	Quality of the surface water	PoM2015 of the Hydrographic District of the River Po	2015
	Livestock load	RICA	2015–2017
	Quantity of irrigation water consumed in the plant production phase	SIGRIAN	2016–2018
	Degree of efficiency of irrigation systems	SIGRIAN	2016–2018
	Distribution efficiency	SIGRIAN	2016–2018
	Energy consumption for lifting	SIGRIAN	2016–2018
	Energy production from hydroelectric production plants	SIGRIAN/ARPAE	2018
Social	Presence of characteristic elements of the irrigation agro-ecosystem	SIGRIAN	2018
	Irrigation infrastructure investments	PSR Emilia Romagna/PSRN	2019
	Producers of quality products	ISTAT	2014–2017
Economic	Net labor productivity	RICA	2015–2017
	Incidence of public aid	RICA	2015–2017
	Land productivity	ISTAT	2015–2017
	Incidence of the added value of agriculture	ISTAT	2015–2017
	Consortium efficiency	SIGRIAN	2016–2018
	Price of water (EWP)	RICA	2015–2017

The soil organic substance content: expresses the percentage of organic substance or organic carbon (C). The parameter was obtained from the Emilia Romagn region map in raster format, averaging the values of the individual cells of the raster;

No. of stations monitored in eutrophic state: No. of monitored stations showing the eutrophic status with respect to the total number of monitored stations;

The quality of the surface water: was calculated by means of the number of rivers in a good environmental state, as defined by the Plan of management 2015 of the Hydrographic District of the River Po, related to the total number of rivers;

Livestock load: Expressed in UBA on hectare, the values reflect the corporate realities within the territory;

Quantity of irrigation water consumed in the plant production phase: was obtained by dividing the cubic meters of water for irrigation purposes by the surface expressed in hectares;

Degree of efficiency of irrigation systems: Percentage of drip and sprinkling irrigated area compared to the total *irrigated area*;

Distribution efficiency: Ratio between the volume of water used and the volume withdrawn;

The energy consumption for lifting: is given by the cost of the energy used (per hectare) for lifting (ratio between the cost of energy and the surface of the entity);

Energy production from hydroelectric production plants: This indicator is obtained from the ratio of the value of the energy produced within the consortium (or region) to the surface (ha);

Presence of characteristic elements of the irrigation agro-ecosystem: Presence of canals with dense vegetation, with scarce vegetation, with absent vegetation (compared to the overall length of the canals);

Producers of quality products: Ratio of the number of producers of quality products to the area in hectares;

Irrigation infrastructure investments: Euros spent for investments in irrigation infrastructure;

Net labor productivity: Ratio between the company's gross operating margin (GOM) and the company's total work units;

Incidence of public aid: Ratio of the amount of public aid (PA, especially CAP) to the company's net income;

Land productivity: Ratio of the value of agriculture production to the agricultural area used

Incidence of the added value of agriculture: Percentage ratio of the added value of agriculture to the total added value;

Consortium efficiency: Ratio of irrigated area to equipped area;

Price of water (*EWP*): Water cost, expressed in EUR/m^3, obtained by dividing the gross margin by the irrigated hectares and, in turn, dividing by the volume of water used per hectare.

All indicators were taken from official and reliable sources, mainly ISTAT, the Italian public research body that deals with general censuses of the population, services and industry, and agriculture; SIGRIAN (National Information System for the Management of Water Resources in Agriculture), which is the database created and managed by CREA-PB (Council for Research in Agriculture and Analysis of the Agricultural Economy, Center for Policies and Bioeconomy), and constitutes the reference for the monitoring of irrigation volumes available to all administrations and bodies competent in the field of water for agriculture, under the Ministry of Agriculture's (Mipaaf) Ministerial Decree 31/07/2015; FADN (Farm Accountancy Data Network), which is an annual sample survey set up by the European Economic Commission in 1965, with EEC Regulation 79/56, updated with the EEC Reg. 1217/2009; various sources such as the 2015 PoM of the Po River hydrographic district, the SINTAI and the regional map of Emilia Romagna. The data reference period is variable and was dictated by the availability of the data by the abovementioned sources.

4.2. Processing Methodologies

As mentioned above, a relative weight was assigned to each indicator according to the AHP method. The weights were attributed so that the sum for each area of sustainability (environmental, social, economic) was equal to 1.

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty, is an effective tool for dealing with complex decision making and may aid the decision maker in setting priorities and making the best decision. By reducing complex decisions to a series of pairwise comparisons and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision.

The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion.

To compute the weights for the different criteria, the AHP starts by creating a pairwise comparison matrix A. The matrix A is an $m \times m$ real matrix, where m is the number of evaluation criteria considered. Each entry a_{jk} of the matrix A represents the importance of the *j*th criterion relative to the *k*th criterion. If $a_{jk} > 1$, then the *j*th criterion is more important than the *k*th criterion, while if $a_{jk} < 1$, then the *j*th criterion is less important than the *k*th criterion. If two criteria have the same importance, then the entry a_{jk} is 1.

The relative importance between two criteria is measured according to a numerical scale from 1 to 9 and may be used to translate the decision maker's qualitative evaluations of the relative importance between two criteria into numbers.

Once the matrix A is built, it is possible to derive from A the normalized pairwise comparison matrix by making equal to 1 the sum of the entries in each column, i.e., each entry a_{jk} of the matrix is computed as:

$$\overline{a_{jk}} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{jk}}. \tag{1}$$

Table 2 shows the indicators with the relative weights.

Table 2. Indicators and the related weights used.

Indicator	Applied Weight
Soil organic substance content	0.13
No. of stations monitored in eutrophic state	0.13
Quality of the surface water	0.04
Livestock load	0.13
Quantity of irrigation water consumed in the plant production phase	0.14
Degree of efficiency of irrigation systems	0.14
Distribution efficiency	0.14
Energy consumption for lifting	0.08
Energy production from hydroelectric production plants	0.08
Presence of characteristic elements of the irrigation agro-ecosystem	0.33
- canals with dense vegetation	0.13
- canals with scarce vegetation	0.07
- canals with absent vegetation	0.13
Irrigation infrastructure investments	0.33
Producers of quality products	0.33
Net labor productivity	0.05
Incidence of public aid	0.05
Land productivity	0.13
Incidence of the added value of agriculture	0.13
Consortium efficiency	0.32
Price of water (EWP)	0.32

Since attributes are measured on different scales, the outputs for the alternatives in terms of attributes must be normalized, i.e., plotted on a scale whose values are between 0 and 1. In this case the normalization was carried out directly by the software for the calculation of the single sustainability index. The territorial sustainability index was calculated using a QGIS plug-in called Spatial Sustainability Assessment Model (SSAM) (Developed by ARPA Umbria and Laboratorio Ambiente, University of Perugia) which uses the algorithm called TOPSIS.

QGIS is a user-friendly open source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo).

TOPSIS was developed by Yoon and Hwang in the year 1981 [33]. The fundamental construct of this methodology is that the various choices ought to have the shortest distance from the best answer and therefore the farthest distance from the negative-ideal answer in some geometric sensation. The largest and smallest values of each attribute are the positive ideal and the negative-ideal solution, respectively, if the attribute is of the type "more is better", and vice versa if the attribute is of the "less is better" type. TOPSIS was used to rank the alternatives in terms of each attribute and produce an overall ranking of alternatives based on the weights for objectives from AHP. In the TOPSIS algorithm the normalized values of each attribute in every alternative are compared to those of the positive- and negative-ideal solutions. The Euclidean distances of each normalized value from the positive- and negative-ideal values is calculated, providing a measure of each alternative's separation from the two extremes. The greatest separation is that between the positive and negative-ideal solutions, and all the other solutions are ordered by separation in relation to these two [26].

For the calculation of the Euclidian distance from the ideal best and ideal worst solution, the formulas used in TOPSIS algorithm are the following:

The separation of each alternative from the positive ideal solution is given as:

$$d_i^+ = \left(\sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^p \right)^{1/p}, i = 1, 2, \ldots, m. \tag{2}$$

The separation of each alternative from the negative-ideal solution is given as:

$$d_i^- = \left(\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^p \right)^{1/p}, i = 1, 2, \ldots, m \tag{3}$$

where $p \geq 1$

v_j^+ = ideal best solution

v_j^- = ideal worst solution

Then it is possible to calculate the relative closeness coefficient (*CC*) to the ideal solution of each alternative, applying the following formula:

$$\mathrm{CC}_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, \ldots m. \tag{4}$$

Based on the decreasing values of the closeness coefficient, alternatives are ranked from most valuable to worst. The alternative having the highest closeness coefficient is selected.

The CC values obtained through SSAM are present in the Supplementary Material, in shapefile format, which can be opened via gis software and supplied on request.

5. Results

The results showed the sustainability performances of the territories through the scores obtained with respect to the individual indicators, classified as environmental, social, and economic. The next step of the analysis made it possible to obtain the degree of sustainability with respect to an overall indicator, which included the environmental, social, and economic aspects of the use of water in agriculture. Although the aggregation of the indicators is often criticized because of the difficulty in interpreting and understanding of the results, it is necessary to provide a benchmark that can guide the implementation of the tools that encourage the sustainable use of water. In any case, the model used allowed us to trace the starting indicators (environmental, economic, and social), making it possible to identify the component that negatively affected the sustainability of a given territory. The QGIS SSAM plug-in permitted us to analyze, both separately and in an aggregate manner, the attributes for the environmental, economic, and social components.

SSAM is a model for assessing sustainability, born from a collaboration between ARPA Umbria and Laboratorio Ambiente of the Department of Agricultural, Food and Environmental Sciences of the University of Perugia.

The method at the heart of this model is of the multicriteria type. These methodologies enable evaluations of several aspects at the same time, which can then be integrated. This method is the ideal tool for sustainable development as it is a multidimensional concept: in fact, the economic, social, and environmental dimensions must be integrated; moreover, even within the individual dimensions there are very different indicators. Therefore, the multicriteria methodology is certainly the most adequate, and these methodologies are part of a large group of decision support tools. SSAM uses the TOPSIS algorithm, which leads to accurate results. The territorial realities are evaluated comparatively. The final product of the elaborations is represented by numerical and tabular outputs, but also by graphical and cartographic data. These outputs represent the environmental, economic, and social sustainability indices, as well as the eventual global sustainability index, which can be obtained by weighting the values of the three indices that make it up.

Figures 2–4 show the level of sustainability for each territorial area.

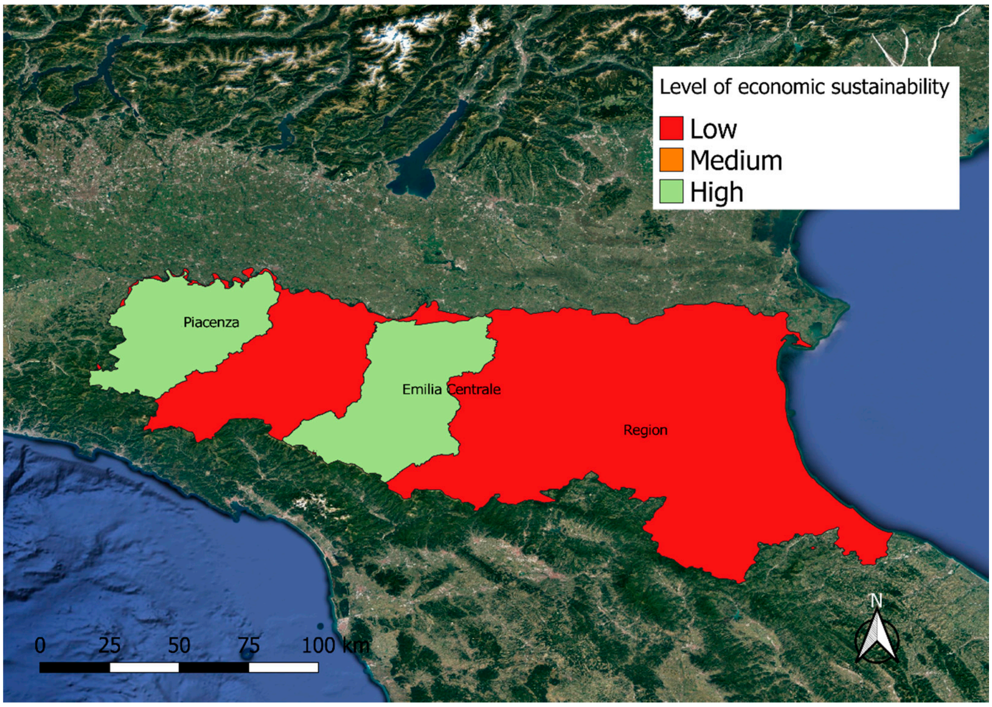

Figure 2. The image shows the level of economic sustainability for each area. Higher values are in green, lower values are in red.

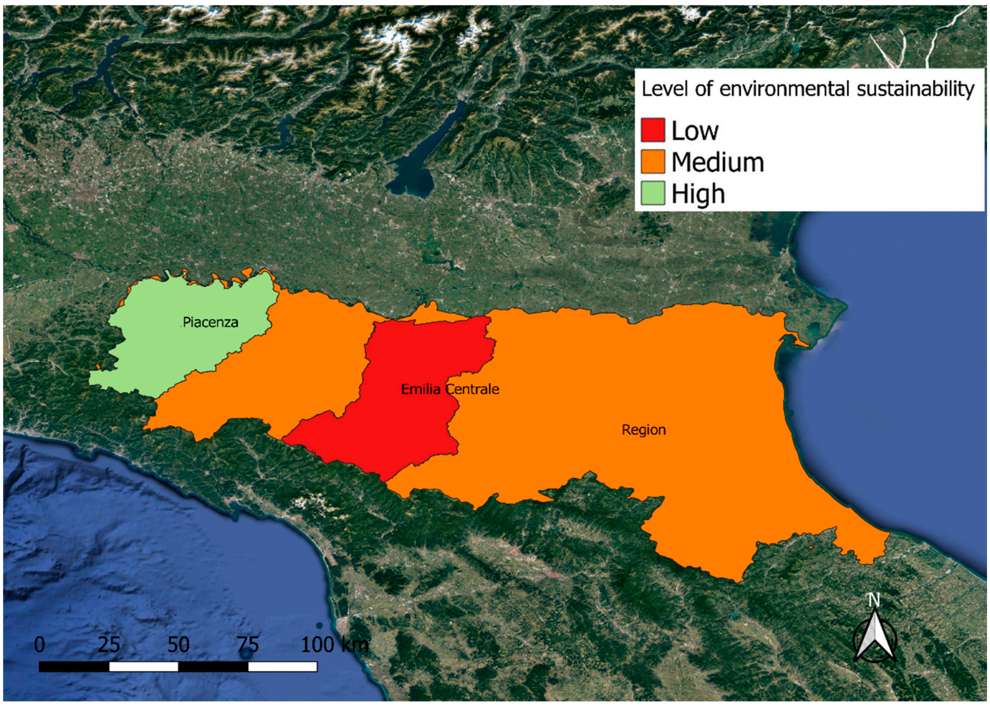

Figure 3. The image shows the level of environmental sustainability for each area. Higher values are in green, lower values are in red.

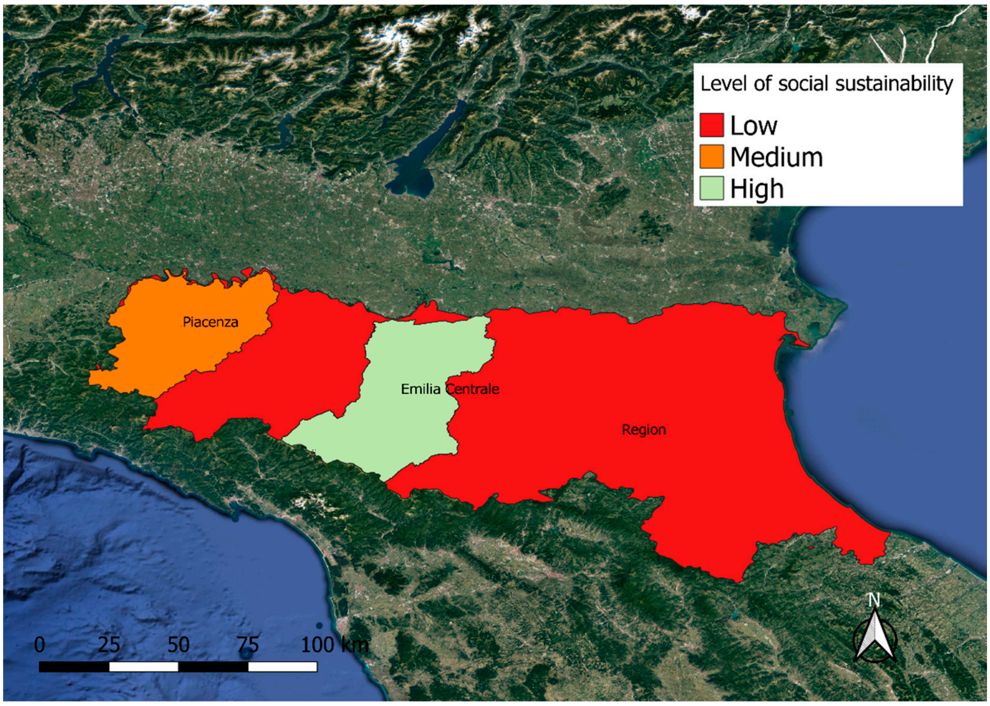

Figure 4. The image shows the level of social sustainability for each area. Higher values are in green, lower values are in red.

In general, the two consortia had levels of economic, environmental, and social sustainability that were higher than the regional average, the only exception being the environmental sustainability of the Emilia Centrale Irrigation and Reclamation Consortium, which was lower than the regional average. This can be mainly attributed to the indicators of distribution efficiency, energy consumption for lifting, and energy production from hydroelectric production plants, which had better values for the region than the consortium of Emilia Centrale. SSAM realized three different maps, one related to the environmental sustainability index, one related to the economic sustainability index, and finally one related to the social sustainability index.

The following graphs illustrate the situation for each component within the territorial areas.

They were generated by SSAM, applying Equation (4), which permitted us to calculate the closeness coefficient.

The first is the so-called Chart of sustainability (Figure 5). In this graph, the y-axis represents the values assumed by the CC, and on the x-axis we find the separated values of the three components (social, economic, environmental). We see, for each of the consortia and the reference region, the three components we analyzed: the economic one in red, the social one in blue, and the environmental one in green. The three components are placed side by side. In this way we see very quickly which entity has, for example, a higher value of social index rather than the environmental index, such as the Emilia Centrale consortium. We also see if the entities have a disequilibrium between the three components. Analyzing the consortia, the economic component seemed to be the predominant one.

The second graph, called Bars of sustainability (Figure 6), presents the same results as the previous one in a different way. Specifically, the three components are overlapped; this results in a visual ranking among the different areas, it points out that the consortia reached higher levels in the sum of the three indices, compared to the region, whose level was much lower. It is already possible to visually predict the general sustainability index. However, the contribution of each individual component is very clear, as they remain with a distinct color. The heights of the two consortia are more or less the same but the contributions of the three components are very different because in the consortium of Emilia Centrale, compared to that of Piacenza, the social component prevailed at the expense of the environmental one.

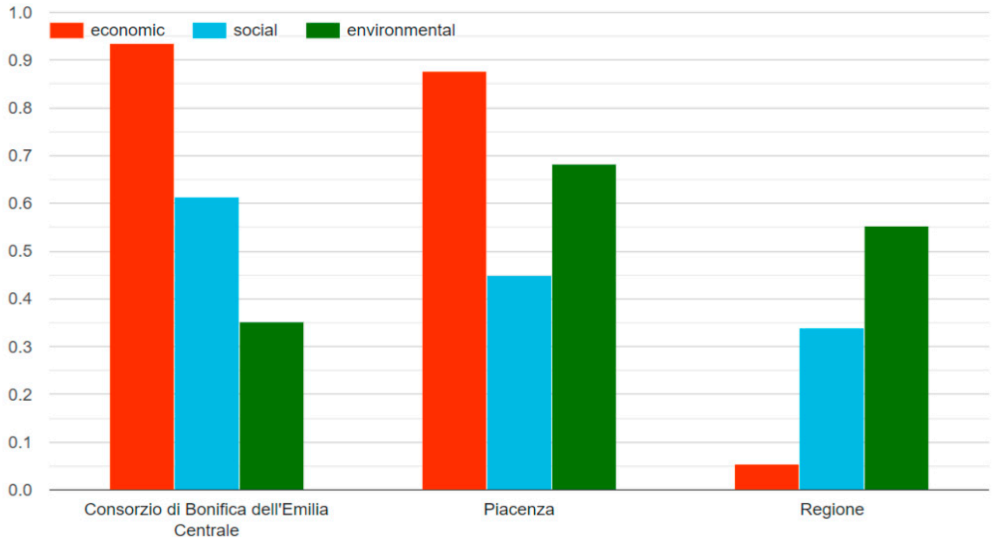

Figure 5. Chart of sustainability. The components of sustainability are separate and individually comparable.

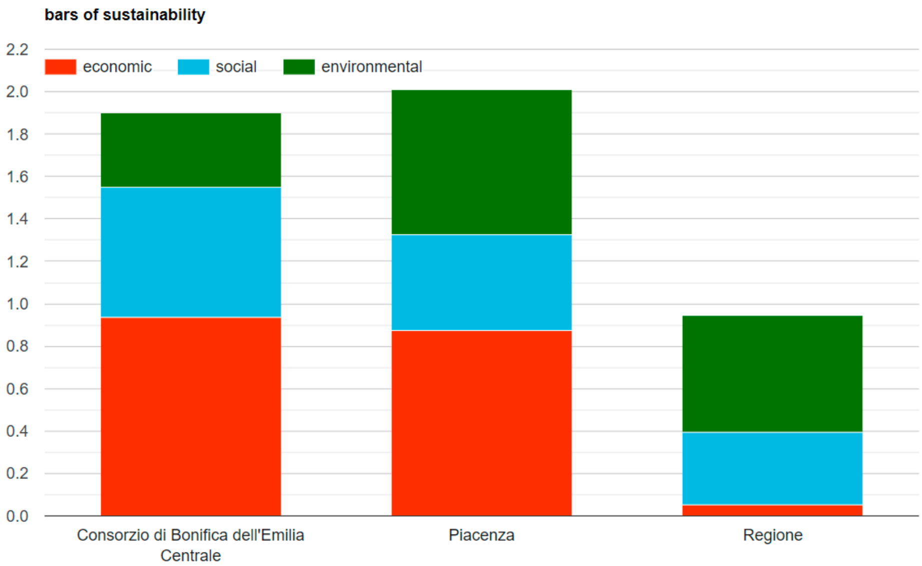

Figure 6. Bars of sustainability, showing the overall degree of sustainability achieved.

The last graph presented is called the Bubble Graph (Figure 7), which presents the same values of the previous two but allows us to see more easily the three dimensions at the same time. On the x-axis we see the values of the economic CC reported. This means that the more an institution is moved to the right, the greater the performance from an economic point of view. On the y-axis we see the value of the social CC reported. It can therefore be easily seen that the Emilia Centrale consortium had excellent economic and social performance. The color of the single bubble instead gives an idea of what the result of the environmental index is: if the color is green, it means a good value (Piacenza), if instead it is red, performances were poor from the environmental point of view (Emilia Centrale).

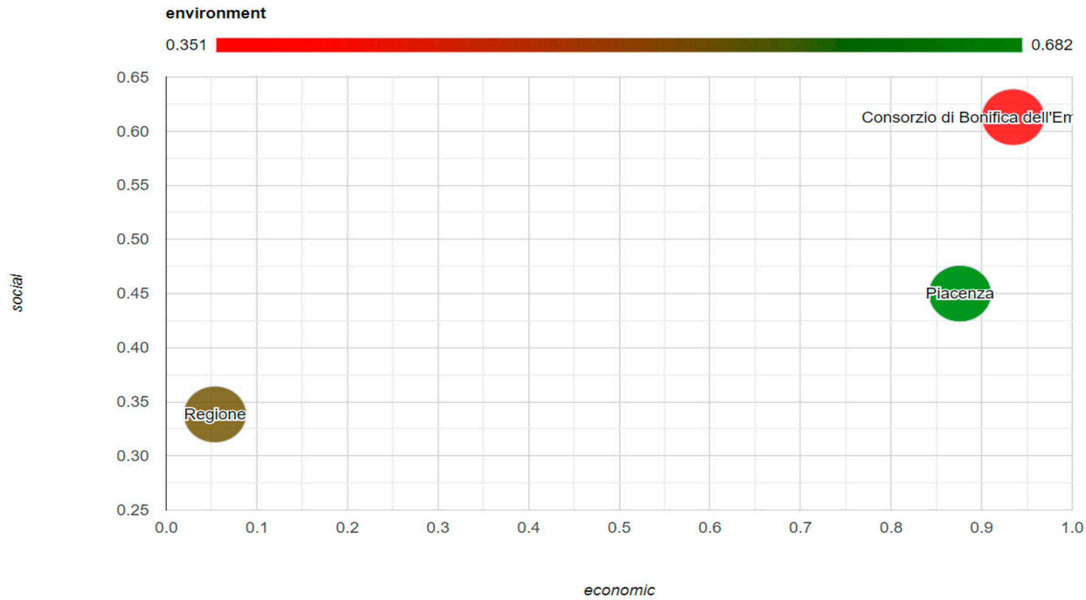

Figure 7. Bubble Graph allows us to see the three dimensions of the sustainability at the same time.

At this point we carried out the assessment of global sustainability by making an overlap of the three components. The overlap was carried out, again through SSAM, by giving the same importance to all three dimensions. A general sustainability map was then generated, shown in Figure 8. As can be seen, despite the poor environmental sustainability of the Emilia Centrale reclamation consortium, both consortia had an excellent general sustainability value when compared with the regional average.

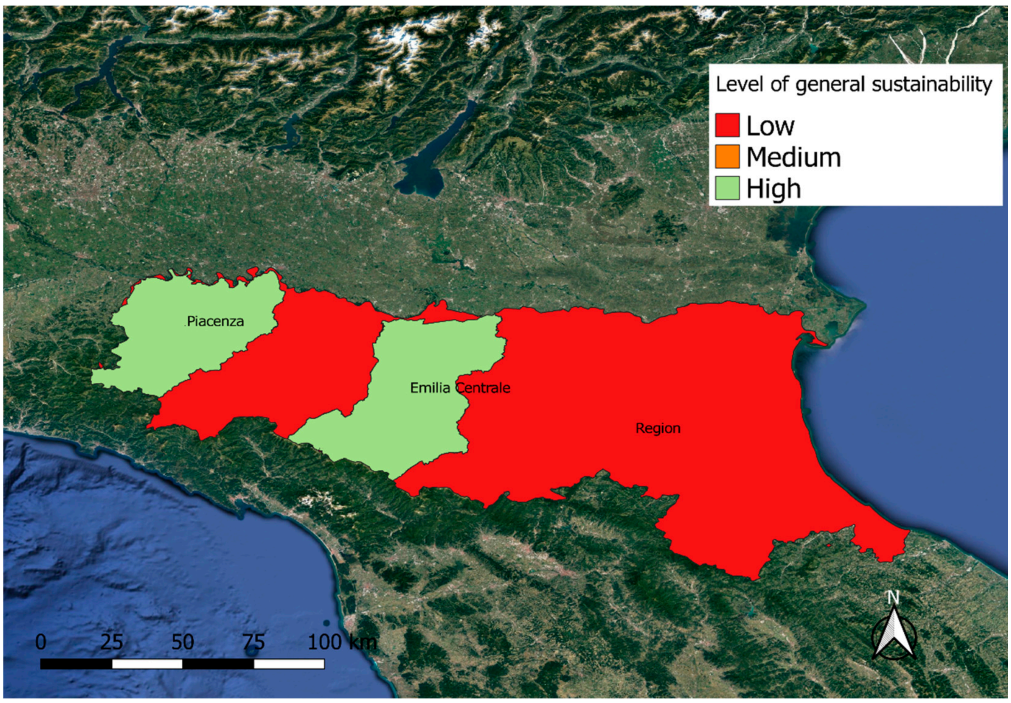

Figure 8. General sustainability map.

6. Discussion

In recent years, socio-environmental issues have become an integral part of the objectives of agricultural policy. The ever-growing demand for the quality, safety, and genuineness of food products; climatic and energy shocks; and social and environmental problems related to sustainable development have contributed to speeding up this process.

The CAP 2023–2027 offers multiple tools that encourage sustainable management, from a social, environmental, and economic point of view, in the agricultural sector (e.g., eco-schemes). “The agricultural sector is a complex system with sound economic, social, territorial and environmental connotations, able to contribute to the achievement of the European Green Deal’s goals. The sector performs important productive functions, within the national and EU economic system, and provides for the safeguard and protection of the territory, of natural heritage and biodiversity, being the cornerstone for territorial, social and economic cohesion” [34]. To correctly direct the choices for the CAP 2023–2027 it is necessary to create a benchmark against which to assess the sustainability of a specific territory/production activity, and the analysis conducted in this article responds to this need, regarding water resources.

Once a sustainability ranking has been established, this work will be useful to the public decision maker (decision support system) who is thus able to make decisions with more information, including technical and not only political ones, and to know where to intervene, where to direct the resources necessary to align in the direction of sustainability those territorial realities that are marginal. This is particularly important at a time like the current one, where at an international level all the countries of the world are working to achieve the objectives of Agenda 2030 (sustainable development goals), which must meet a series of requirements to reach a more widespread world sustainability level.

The synthetic indicator makes it possible to conduct an overall assessment. As seen from the results, the low scores obtained in one dimension can be offset by high scores in another one. This allows us to consider the situations in which, although the technical efficiency of the water use is low, positive externalities are realized, as in the case of uncoated canals. This tool can help us to evaluate a starting situation, an ongoing one, and the results achieved.

The work is in line with the efforts of international and European initiatives to measure sustainability. At an international level, an example is the System of Environmental–Economic Accounting (SEEA), a framework that integrates economic and environmental data to provide a more comprehensive and multipurpose view of the interrelationships between the economy and the environment and the stocks and changes in stocks of environmental assets. The Committee on Sustainable Assessment (COSA), founded by the International Institute for Sustainable Development and the United Nations, is also oriented toward the measurement of sustainability. At the European level, the ECI, European Common Indicators, a local sustainability monitoring initiative promoted by the European Commission, aims to provide a practical tool for evaluating and comparing the sustainability of the policies of various local authorities. Furthermore, Eurostat has developed indicators for measuring sustainable development with respect to the goals of Agenda 2030.

In conclusion, the synthetic indicators here developed and applied to a specific case study are certainly a support system for important and urgent decisions, highlighting the criticality and potential of a certain territory. The methodological tool allows researchers to report the distance between the various realities analyzed as a function of certain predetermined indicators. The model is also effective at simulating alternative scenarios in order to evaluate the effects of interventions aimed at improving environmental services and/or socioeconomic issues, highlighted thanks to the calculation of the individual indicators.

7. Conclusions

The work presented made it possible to compare the sustainability practices of the reclamation consortia. The choice of this area allowed us to effectively guide the policies, as the current trend is to reward the work of the consortia and certify it through the creation of sustainability marks aimed at the consortia themselves.

The integrated approach of GIS (and SSAM software) and MCDA allowed the creation of sustainability maps, which are very useful for guiding policy makers and important if many areas are evaluated. It also provided the opportunity to compare in an integrated way and to separate the three components of sustainability, giving us the opportunity to focus attention on a possible deficient component. The results obtained, specifically for the production activity and production area, can be used to evaluate the sustainability of a specific territory activity as regards the use of water resources. In this way it will be possible to identify any critical issues and encourage corrective actions that promote a sustainable use of water resources in agriculture. Furthermore, the proposed indicators and methodology can become a reference point for the eventual creation of sustainability marks linked to the use of water and intended for consortia. In fact, the policies tend to enhance the work of the Irrigation and Reclamation Consortia, due to the useful management service of the water resources they offer, and this has already led to the desire to create a sustainability mark suitable for this purpose.

It should be noted that this represents a preliminary study, which obviously offers an overview but does not allow us to present a real picture of the situation in the Emilia Romagna region, as we have limited the study to consideration of only two of the numerous consortia of Emilia Romagna. The decision to consider only two consortia was driven by the availability of the data. The reference years of the various indicators were not always the same, and indicators were linked to the years in which most of the data were available. It would be appropriate to promote policies in this area as well, encouraging consortia to carry out constant monitoring and provide all the data in their possession. It would be fruitful to continue the study by also gathering the necessary information for the other consortia in the region and making an overall comparison. The same methodology can be applied to the other regions, as well. Moreover, a more detailed articulation of the landscape indicator can improve the analysis, identifying the elements of historical–cultural–recreational value through research on the territory.

Despite this, our work constitutes an important integration of the methodologies for the analysis of territorial sustainability linked to water resources; the reasons are mentioned above: the choice of territorial area that coincides with that of the consortia; and the integration of technical problems related to water-use efficiency and territorial problems, in order to integrate the positive and negative impacts related to the use of water in agriculture relating to all dimensions of sustainability. However, the result obtained is valid and reflects the assessments of sustainability at a territorial level; therefore, different territorial realities can be evaluated and compared.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13158221/s1, The data presented in this study are available on request from the corresponding author.

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Data Availability Statement: All indicators were taken from official and reliable sources. Below is a list of the sources used, with the availability of the data and the access date. Soil organic substance content, available in a publicly accessible repository on https://ambiente.regione.emilia-romagna.it/it/geologia/suoli/proprieta-e-qualita-dei-suoli/carbonio-organico-immagazzinato-nei-suoli, accessed date 2 March 2021. No. of stations monitored in eutrophic state, available on http://www.sintai.isprambiente.it/faces/public/NIT/home.xhtml, accessed date 2 March 2021. Quality of the surface water, available in a publicly accessible repository on https://www.adbpo.it/PianoAcque2015/Elaborato_12_RepDatiCarte_3mar16/PdGPo2015_All122_Elab_12_DBase_3mar16/, accessed date

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