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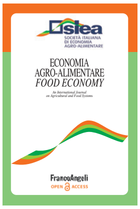

Sustainable water management in viticulture under climate stress: Irrigation requirements and potential of controlled water deficit

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Abstract

Climate change is forcing a fundamental revision of water management in agriculture, particularly in Mediterranean viticulture. In Italy, rising average temperatures, irregular rainfall patterns, and the frequent occurrence of extreme events are reducing water availability and quality, compromising both yields and the quality of grape and wine production. This study presents a technical and scientific analysis of the current state of irrigation in Italian vineyards, integrating data from the 7th General Agricultural Census by ISTAT (2020) with information from the SIGRIAN system, and adopting a geospatial approach to estimate the actual water requirements of grapevines. Furthermore, the benefits of Regulated Deficit Irrigation (RDI) are explored as a means to increase water use efficiency without compromising enological parameters. The results highlight significant territorial differences in water needs and irrigation management, underscoring the necessity for adaptive policies and site-specific technologies.

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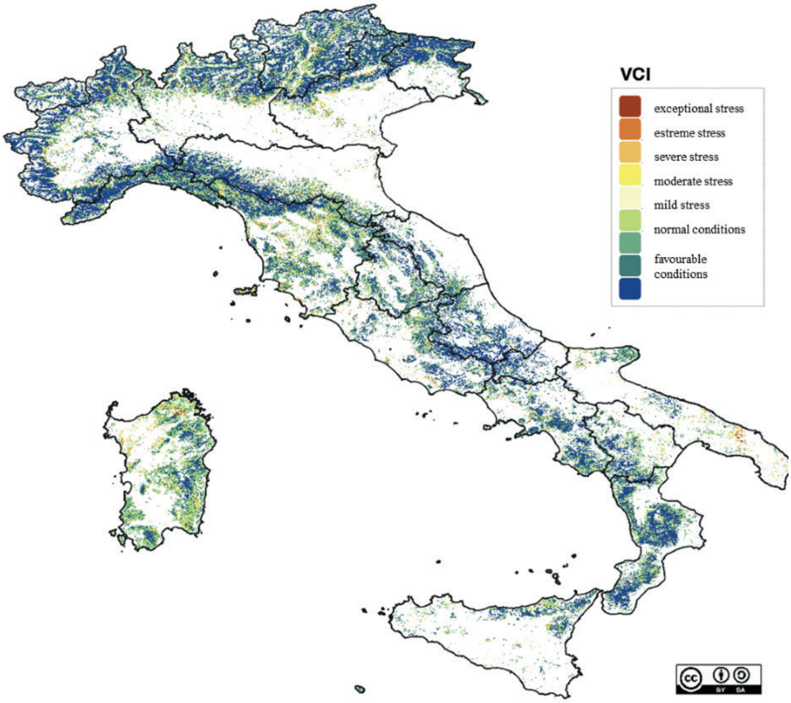
Introduction

The Italian wine sector, one of the most significant worldwide in terms of vineyard area, added value, and territorial identity, is currently severely threatened by increasing climate instability. According to data from the Copernicus Climate Change Service, 2024 was the warmest year ever recorded in Europe. Italy has also shown clear signs of this warming trend. During the summer of 2024, many areas in southern Italy and along the Mediterranean coasts experienced temperatures exceeding 38 °C, while the 2024-2025 autumn-winter season was characterized by anomalously persistent warmth. Water stress, resulting from both low precipitation and increased evapotranspiration, negatively affects vegetative growth, phenology, and grape must quality. These impacts are also detectable through the analysis of vegetation indices such as the Vegetation Condition Index (VCI) (Figure 1), which highlighted particularly severe criticalities in the southern regions and the islands (Magno, 2025).

Figure 1 - Vegetation Condition Index (VCI) – June 2025



Source: CNR IBE Drought Observatory (2025).

As a result of the increasing pressure exerted by climate change on water resources, a significant rise in irrigation demand is expected for the main Mediterranean crops, including maize, wheat, and grapevines, with estimated increases ranging from 10% to 16% between 2035 and 2065. This trend is exacerbating water scarcity at the national level, intensifying competition among various water uses – agricultural, domestic, and energy-related – and jeopardizing the sustainability of agricultural production. Within this context, viticulture emerges as one of the most vulnerable crops to climate variations, owing to its high sensitivity to water and heat stress and the pivotal role of enological quality along the production chain.

Italian wine producers are currently facing profound structural and environmental transformations that impact the entire production cycle, from varietal and rootstock selection and water resource management to grape maturation for the determination of wine quality attributes. Recent studies have investigated these processes extensively. For instance, Alba *et al.* (2024) demonstrated that global warming is altering grapevine phenological cycles, directly affecting grape composition and consequently wine quality. Meanwhile, Esposito *et al.* (2024) underscore the critical role of technological innovation and institutional governance in fostering integrated and sustainable management of agricultural water resources. With climate change becoming increasingly apparent, the scientific community is intensifying research on sustainable and climate-resilient grapevine varieties and viticultural practices aimed at mitigating the adverse effects of changing climatic conditions. Di Vita *et al.* (2024) provide a noteworthy example within this research domain, focusing specifically on consumer perception and acceptance of innovative strategies designed to enhance the adaptability of viticulture to climate change. The rapid advancement of climate change necessitates a systematic examination of viticulture, both in Italy and Europe. Gerbi and De Paolis (2025) highlight how agronomic conditions of the main Italian wine-growing areas are substantially altered, leading to imbalances between technological and phenolic maturation, early harvest times and a worsening of the balance between sugars, organic acids and aromatic compounds. From a medium-long term perspective, it is therefore strategic to also act on the genetic front. The international literature has been reviewed by Baltazar *et al.* (2025) and they have highlighted how varietal selection, and the introduction of more resilient clones or cultivars can serve as fundamental tools for adapting to climate change. Another critical problem is the scarcity of water resources: the intensification of stressful situations requires adaptation strategies such as emergency irrigation, which can only buffer such situations but highlight problems of economic and ecological sustainability, especially in a scenario of competing uses (Bentivoglio *et al.*, 2024).

In response to these challenges, this study aims to provide a comprehensive analysis of the current state of vineyard irrigation in Italy, with the goal of identifying effective adaptation strategies to cope with increasing climate variability. Particular attention is given to the potential of advanced irrigation technologies, emphasizing the role of smart irrigation systems and Regulated Deficit Irrigation (RDI) as promising approaches to enhance water use efficiency while maintaining enological quality.

The methodological framework integrates official data sources, including the 7th General Agricultural Census (ISTAT, 2020) and technical-operational datasets from the National Information System for Agricultural Water Resource Management (SIGRIAN). This integration enables a spatially detailed reconstruction of irrigated vineyard areas and their actual water requirements, distinguishing between collective and autonomous water supply systems.

Beyond quantifying irrigated surfaces, the study estimates irrigation volumes required for grapevine cultivation through spatially explicit models that incorporate climatic, topographic, and soil parameters. Given the increasing meteorological uncertainty, adopting harmonized national methodologies is crucial for improving the accuracy of irrigation demand estimations, facilitating interregional comparisons, and ensuring consistency in territorial-scale assessments.

The findings constitute a valuable knowledge base to better inform adaptation strategies, investment planning, and water resource allocation, aligning with the objectives of the Common Agricultural Policy (CAP) and the European regulatory framework on sustainable water management (Díaz *et al.*, 2021; Kyriakopoulos *et al.*, 2023).

Finally, although climate change represents a significant challenge for the viticulture sector, it simultaneously acts as a catalyst for the adoption of technical and managerial innovations. This study also explores how irrigation practices in viticulture are evolving in response to increasing water scarcity and examines the contribution of smart technologies, including RDI systems, in enhancing resource use efficiency and sector resilience.

1. Economic and territorial evolution of irrigated viticulture

Climate change is driving profound structural and functional transformations in Italian viticulture, a strategic sector for national agriculture both economically and in terms of identity. Rising average temperatures, increased frequency of extreme events (such as prolonged droughts, heatwaves, and intense rainfall), and growing inter- and intra-annual climate variability are significantly affecting vine phenology, grape quality, and agronomic practices adopted by winegrowers.

Among the most tangible effects is a progressive shift of vineyards towards hilly or mountainous areas, in an effort to mitigate thermal stress and preserve the organoleptic characteristics of wine production. This shift is associated with local ecosystem imbalances, potentially impacting the socio-economic system linked to high-quality wine production (Guadagno, 2012).

To assess the recent evolution of irrigated viticulture in Italy, an analysis was conducted using data from the 6th and 7th General Agricultural Censuses (ISTAT, 2020).

Regarding structural aspects, the 2020 Agricultural Census data indicate over 52,000 farms in Italy with irrigated vineyard areas. However, the territorial distribution of these farms is highly uneven, reflecting regional differences in irrigation intensity and production characteristics. This analysis adopts the territorial classification based on ISTAT's official macro-geographical areas: North-West, North-East, Centre, South, and Islands.

Northeastern Italy remains the area with the highest concentration of irrigated vineyards, hosting nearly half of Italy's irrigated wine farms, led by Veneto (over 10,000 farms), followed by Trentino-Alto Adige and Emilia-Romagna. This high concentration reflects the area's strong viticultural specialization, supported by an efficient irrigation infrastructure system.

In Southern Italy, the distribution is heavily concentrated in Apulia, which alone accounts for over one quarter of the national total. Other southern regions such as Campania, Calabria, and Abruzzo also show a significant presence of irrigated farms, albeit in smaller numbers.

Central Italy exhibits a more limited presence of irrigated vineyards, both in absolute and relative terms. Viticulture in these areas tends to be less dependent on irrigation and often characterized by smaller farm sizes. The most representative regions are Lazio and Tuscany.

Finally, in Northwestern Italy, a relatively modest yet homogeneous presence of irrigated vineyards is observed across Piedmont, Lombardy, Liguria, and Valle d'Aosta. The major islands (Sicily and Sardinia) also have a significant number of irrigated farms, consistent with the historical and productive importance of the viticulture sector in these regions (Table 1).

Table 1 - Farms with irrigated vineyard areas (n.) - Year 2020

Italy	**Farms (n.)**	**%**
North-West	2,289	4.3
North-East	25,661	48.4
Centre	1,593	3.0
South	16,504	31.2
Islands	6,931	13.1
Total	**52,978**	**100.00**

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

The intracensal comparison reveals a significant increase in irrigated vineyard areas, which grew from 176,007 hectares in 2010 to 223,779 hectares in 2020 (+27.1%). In contrast, the total irrigated area across all crops experienced a contraction of 2.5%, decreasing from 2,418,921 to 2,358,264 hectares during the same period.

This trend confirms the growing importance of irrigation in the viticulture sector, likely attributable both to increased exposure to water stress events and to the need to meet the high-quality standards demanded by the market. Furthermore, this expansion can be interpreted as indicative of a process of technical modernization and increasing specialization among Italian wine-producing farms (Table 2).

Table 2 - Irrigated areas for crops – vines (ha). Years 2010 and 2020

Crops	**Irrigated area 2010 (ha)**	**Irrigated area 2020 (ha)**	**Variation 2010/2020 (%)**
Vines	176,007	223,779	*27.1*
Total	**2,418,921**	**2,358,264**	*–2.5*

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

The disaggregated analysis of irrigated vineyard areas, based on data from the 2020 General Agricultural Census, allows for an in-depth examination of the territorial dynamics characterizing the growth of the viticulture sector during the 2010-2020 decade. The territorial classification, based on the official ISTAT macro-geographical areas, highlights a strong concentration of irrigated vineyard surfaces in the North-East and South.

Among individual regions, Apulia confirms its leading position with 64,589 hectares (28.9% of the national total), followed by Veneto with 51,511 hectares (23.0%) and Sicily with 25,638 hectares (11.5%). Significant irrigated areas are also found in Emilia-Romagna (25,697 hectares, 11.5%), Friuli-Venezia Giulia (15,026 hectares, 6.7%), and Trentino-Alto Adige (12,541 hectares, 5.6%).

The aggregated distribution by macro-area shows that:

- North-East regions (Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia-Romagna) account for 46.8% of the national irrigated vineyard area (approximately 104,787 hectares);
- South regions (Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria) total 73,113 hectares (32.7%);

- Islands (Sicily and Sardinia) collectively reach 32,702 hectares (14.6%);
- Centre (Tuscany, Umbria, Marche, Lazio) amounts to 9,229 hectares (4.1%);
- North-West (Piedmont, Valle d'Aosta, Liguria, Lombardy) totals 4,458 hectares (2.0%).

Based on these data, it can be stated that the North-East represents the geographical area with the highest concentration of irrigated viticulture, covering nearly half of the national extent. This is followed by the South and the Islands, which together account for approximately 47% of the total. This distribution reflects the combination of climatic factors, infrastructural availability, and regional specialization in wine production (Table 3).

Table 3 - Irrigated area with vines (ha) - Year 2020

Italy	**Irrigated area (ha)**	**%**
North-West	4,458.33	1.99
North-East	104,775.61	46.82
Centre	9,229.63	4.12
South	72,613.46	32.45
Islands	32,702.02	14.61
Total	**223,779.05**	**100.00**

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

In Italy, a very large share of irrigated vineyard areas – approximately 95% – lacks specific information on the type of irrigation system used, according to data from the 2020 Agricultural Census. This information gap represents a significant obstacle to assessing the technical and environmental performance of irrigation systems employed in the wine sector.

Among the declared types, the most common are:

- sprinkler irrigation, adopted in a minority yet notable portion of the reported areas;
- micro-irrigation, typically associated with drip or low-flow systems, offering potentially high efficiency in terms of water savings;
- surface runoff irrigation, a traditional technique still present in some areas.

Less suitable methods, such as flooding, are marginal and statistically negligible. The limited diffusion of documented advanced techniques, and especially the large share of unclassified areas, highlight the need to update and enhance existing information systems to support more informed and sustainable irrigation decisions (Table 4).

Table 4 - Irrigation systems - Year 2020

Irrigation systems	No irrigation systems (ha)	Surface runoff and lateral infiltration (ha)	Submersion (ha)	Aspersion (ha)	Micro-irrigation (ha)	Other systems (ha)	Total (ha)
Vines	212,199.88	1,445.92	51.76	7,484.85	1,384.55	1,212.09	**223,779**

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

The intercensal analysis of the number of farms with irrigated vineyard areas active in both 2010 and 2020 allows the evaluation of the structural stability of the Italian irrigated viticulture sector, as well as the identification of possible dynamics of abandonment, reconversion, or business reorganization that occurred over the decade.

Overall, 35,930 farms with irrigated vineyards were active in both censuses. Their regional distribution highlights greater continuity in well-established and highly specialized wine-producing areas, such as:

- Apulia (9,254);
- Veneto (6,505);
- Emilia-Romagna (4,405);
- Sicily (3,369).

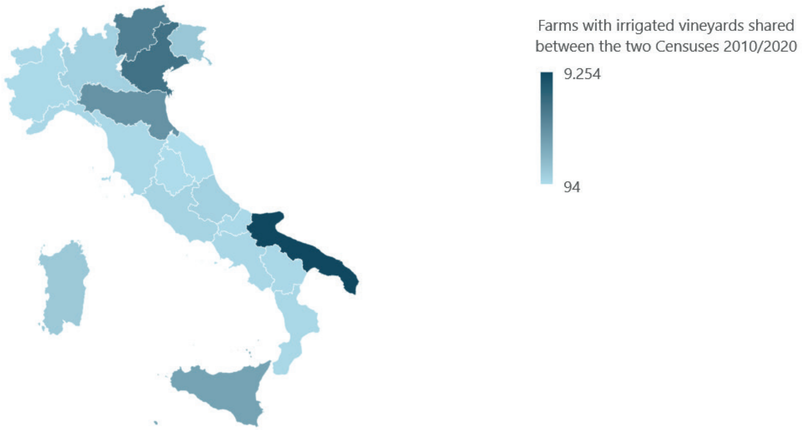
These territories exhibit a stable production structure, supported by a consolidated viticultural tradition and relatively organized irrigation systems.

Conversely, regions such as Umbria (94 farms), Marche (100 farms), Molise (213 farms), and Aosta Valley (296 farms) show much lower levels of business continuity. This reduced persistence can be interpreted either as an indicator of a lower incidence of irrigation in local vineyards or as a sign of productive restructuring and crop conversion processes.

Overall, the northern and north-central regions show greater stability in the number of irrigated vineyards, whereas the South presents a more heterogeneous situation. Apulia represents a significant exception due to its high number and continuity of farms, while other southern regions – particularly Calabria and Basilicata – display lower levels, reflecting a less structured incidence of irrigation within the local production structure (Figure 2).

From an economic perspective, to estimate the potential annual value of Italian wine production, the average Standard Output (SO) indicator was adopted. This metric, calculated based on yields and average market prices, is standardized at the European level and enables comparisons of economic productivity across crops, farming systems, and territorial contexts, providing a useful reference for structural analyses and profitability assessments.

Figure 2 - Distribution of farms with communal irrigation systems – 2010-2020



Source: CREA data processing based on data from the ISTAT General Agricultural Census. 2010-2020 (2025).

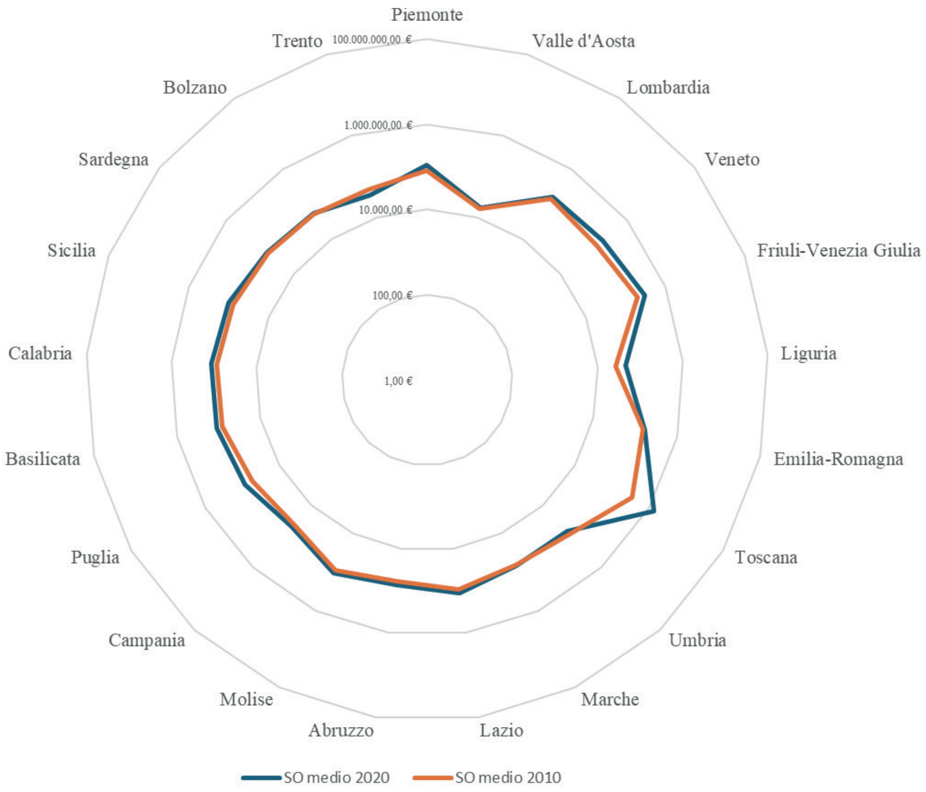
Specifically, the estimate considered the set of farms active with irrigated vineyard areas in both 2010 and 2020, to evaluate the evolution of economic productivity over the decade under consistent structural conditions. At the national level, the average SO value for these farms registered a significant increase of +29%, reflecting a general process of strengthening competitiveness and enhancing the commercial value of the sector.

Among the regions showing the most dynamic performance, Tuscany stands out with an SO increase of +75.8%, followed by Veneto, Friuli-Venezia Giulia, and Apulia. These results indicate an evolutionary process affecting both productive aspects and those related to the quality and marketing of wines, in a context increasingly oriented towards high added-value markets.

Conversely, negative trends were observed in some areas, including Umbria and the Autonomous Province of Trento, which recorded a decrease in average SO of –20.6% and –39.4%, respectively. These trends may be associated with specific transformations in the production fabric, changes in market outlets, or difficulties in technological reconversion.

Overall, farms located in the North-East and North-Central regions tend to show higher average SO levels compared to those in the South. However, some southern realities, particularly Apulia, show encouraging signs of economic growth, confirming the existence of competitive development pathways even in historically less structured contexts (Figure 3).

Figure 3 - Average of Standard Output of irrigated farms with wine in common. Years 2010-2020



Source: CREA data processing based on data from the ISTAT General Agricultural Census. 2010-2020 (2025).

2. Materials and methods

The objective of the developed methodology is to estimate the actual irrigation water requirements of vineyards in Italy through a spatially explicit and standardized approach at the national scale, using the year 2020 as the temporal reference for the analysis. Given the strategic importance of viticulture within the Italian agricultural system and its high vulnerability to climate change impacts, it is essential to have reliable and harmonized analytical tools to support irrigation planning and guide effective adaptation strategies.

The adopted approach is based on the integration of census and agro-climatic data, aiming to overcome information fragmentation and provide a coherent and comparable estimate of irrigation volumes required by vineyards across different territorial contexts. This standardization is particularly important to ensure a homogeneous assessment of actual irrigation demand at the national level, facilitating comparisons between regions and the identification of priority interventions from the perspectives of efficiency and sustainability (Andrenelli *et al.*, 2025; Ortuani *et al.*, 2019).

2.1. *Materials: WebGIS SIGRIAN e ISTAT*

The analysis is based on the integration of two main data sources: the National Information System for the Management of Water Resources in Agriculture (SIGRIAN) and the official dataset of the Italian National Institute of Statistics (ISTAT). The objective is to coherently estimate the actual irrigation water requirements of Italian viticulture at a territorial scale.

*Web*GIS SIGRIAN

SIGRIAN constitutes the main geographic information system (GIS) for the national irrigation sector, developed and managed by CREA – Policies and Bioeconomy (CREA PB). It collects, archives, and makes available both alphanumeric and spatial information related to water management in agriculture, through collaboration among Regions, reclamation consortia, and other managing bodies. The data are organized in a geodatabase structured by territorial units, enabling the association of technical variables (e.g., flow rates, volumes, crops) with specific portions of the national territory.

The spatial unit adopted for this study is the irrigation district[1], defined as the elementary portion managed by each Consortium. For each district, the official shapefile available in the SIGRIAN WebGIS was used, to which the corresponding Annual Specific Volume (ASV) values, expressed in m^3/ha/year, were associated. The ASV represents the average annual volume of water distributed per hectare, calculated based on the actual pedoclimatic, crop, and management conditions of the district. Therefore, it is a direct indicator of real irrigation water requirements, useful for a quantitative and spatially explicit representation of irrigation demand at the national scale.

1. Division of the irrigation area and therefore of the Local Agency for Water Management, whose criteria vary greatly. In general, the subdivision is based on the development of the distribution network, i.e., the district includes an area supplied by its own distributor (CREA PB, 2020).

ISTAT

ISTAT represents the main official source of statistical data in Italy. In the context of the present study, data from the 7th General Agricultural Census (2020) were utilized, with particular reference to the irrigated Utilized Agricultural Area (UAA) by crop and by municipality.

These data enabled the quantification of the spatial distribution of irrigated vineyard areas across the entire national territory, providing essential information for the calculation of territorial irrigation requirements. The association between irrigated vineyard UAA data (at the municipal level) and the ASV derived from SIGRIAN allowed for the estimation of total irrigation volumes by geographic area, and the construction of a synoptic and standardized framework of irrigation pressure in the Italian viticultural sector.

2.2. *Vineyards irrigation requirements*

The methodology developed in this study is structured into four main phases, aimed at estimating the actual irrigation requirements of vineyards in Italy through a standardized geospatial approach:

1. classification of water supply modes, distinguishing between areas managed collectively, through Irrigation Water Services (IWS)[2] and those under Self-Supply (SS)[3];
2. definition of homogeneous areas at the national level based on climatic, physiographic, biogeographic, and hydrographic characteristics, through the overlay of environmental variables (altitudinal bands, ecoregions, river basins);
3. assignment of a unique average ASV value to vineyards within each homogeneous area, based on SIGRIAN data;
4. calculation of the specific irrigation requirement for vineyards as the product of the municipal-level irrigated UAA and the average ASV value corresponding to the respective area.

For the agricultural component, data from the 7th General Census of Agriculture were used, including:

- the irrigated UAA by crop category, available at the municipal level;

2. The set of activities and infrastructures for the supply and distribution of water for irrigation purposes, managed according to criteria of efficiency, sustainability, and current regulations.

3. Farms that independently meet their irrigation water needs by using their own water resources, such as wells, rainwater harvesting, or small reservoirs, without relying on external water supply services.

- the official ISTAT altitudinal bands[4];
- the Italian ecoregions[5], hierarchically subdivided into subsections, sections, provinces, and divisions (according to the national classification).

These data were integrated with geospatial information provided by SIGRIAN 2020, in particular the shapefile of irrigation districts, each associated with an ASV expressed in m³/ha/year per crop. Through vector overlay in a GIS environment, an intersection was performed between the polygons of the SIGRIAN districts and the ISTAT (2020) municipal administrative boundaries, thus enabling the assignment to each municipality (or portion thereof) of the prevailing water supply modality (Collectively, thus through IWS – or SS) (Galeotti *et al.*, 2025; Manganiello *et al.*, 2022).

However, in some areas of the country, SIGRIAN data are incomplete or missing. To overcome this limitation, homogeneous areas were delineated by overlapping altitudinal bands and ecoregions to extend the average ASV value of known districts to contiguous territories with similar pedoclimatic conditions (Ahmadpour *et al.*, 2022; Busschaert *et al.*, 2022). In the absence of data at the subsection level, a hierarchical criterion was applied to extend the average to higher levels (subsection → section → province → division).

Calculation formula

The irrigation requirement for vineyards was then calculated first at the municipal level and subsequently aggregated by macro-areas, as the product of the irrigated vineyard area and the associated mean ASV value, according to the following expression (1):

$$\textit{Total Irrigation Requirements}_{\textit{Geographical area}} = \Sigma \left(\textit{Area}_{\textit{vineyard, municipality}} \cdot \textit{Unit Irrigation Requirements}_{\textit{vineyard, municipality}}\right) \quad (1)$$

Where:

- *Total Irrigation Requirements*$_{\textit{Geographical area}}$ = The total irrigation requirement for vineyards in the considered geographical area was calculated as the sum of the irrigation needs (expressed in m³/year).
- *Irrigated Area*$_{\textit{vineyard,municipality}}$ = Irrigated vineyard area (ha) in the municipality;

4. Main Geographical Statistics of Municipalities-ISTAT.

5. Areas identified based on a hierarchical and divisive classification of the territory into units with increasing levels of homogeneity, consistent with specific combinations of climatic, biogeographic, physiographic, and hydrographic factors that influence the presence and distribution of different species, communities, and ecosystems. Classification of Municipalities according to Italian Ecoregions – ISTAT.

- *Unit Irrigation Requirements*$_{vineyard,municipality}$ = ASV for vineyards in the considered municipality (m³/ha/year).

3. Results and discussion

The methodology described in Section 2.2 enabled the results summarized in Tables 5 and 6. The national irrigation water requirement for grapevine cultivation in 2020 was estimated at 1,122,037,753.37 m³/year, resulting from the combined contributions of IWS and SS sources. Specifically, as shown in table 5, the IWS system accounted for 516,520,454.76 m³/year, corresponding to 46.03% of the national requirement, while SS irrigation (Table 6) represented the predominant share with 605,517,298.60 m³/year (53.97%). The spatial distribution of irrigation water requirements shows a clear predominance of North-East Italy area in both supply systems. This area is the main consumption basin, with 474.2 million m³/year irrigated through IWS (91.81% of the volume distributed through the network) and 470.4 million m³/year under SS irrigation (77.69% of the total SS). This concentration reflects both the significant extension of vineyard areas in the North-East and the high unit irrigation requirement, 8,681.66 m³/ha/year for IWS and 8,112.33 m³/ha/year for SS, respectively.

Southern Italy ranks second in terms of total irrigation volumes for both systems, with percentages lower than those of the North-East (3.46% for IWS and 10.6% for SS). In this area, lower unit requirements are also observed,

Table 5 - Unit and total irrigation water requirements per geographical area through Irrigation Water Service (IWS)

Geographical area IWS	**Area (ha)**	**Unit Irrigation Requirements (m³/ha/year)**	**Total Irrigation Requirements (m³/year)**	**Total Irrigation Requirements (%)**
Centre	443.99	2,608.11	448,293.07	0.09
Islands	4,491.67	1,257.58	6,266,776.80	1.21
North-East	55,327.55	8,681.66	474,206,497.05	91.81
North-West	1,940.55	7,840.31	17,751,574.43	3.44
South	16,313.97	2,969.54	17,847,313.41	3.46
Total	78,517.73	6,726.29	516,520,454.76	100.00

Source: CREA processing of ISTAT General Agricultural Census data (2020) and SIGRIAN (2020).

Table 6 - Unit and total irrigation water requirements per geographical area under Self-Supply Irrigation System (SS)

Geographical area SS	Area (ha)	Unit Irrigation Requirements (m³/ha/year)	Total Irrigation Requirements (m³/year)	Total Irrigation Requirements (%)
Central	8,785.64	5,086.57	15,995,964.73	2.64
Islands	28,210.35	1,167.99	34,076,177.42	5.63
North-East	49,448.06	8,112.33	470,433,753.58	77.69
North-West	2,517.78	8,665.86	20,801,149.44	3.44
South	56,299.49	4,722.59	64,210,253.42	10.60
Total	145,261.32	6,437.02	605,517,298.60	100.00

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020) and SIGRIAN (2020).

with values of 2,969.54 m³/ha/year for surfaces served by IWS and 4,722.59 m³/ha/year for those under SS.

Central Italy stands out for a marginal irrigation demand in both systems, with volumes below 450,000 m³/year for IWS (0.09% of the total) and approximately 16 million m³/year for self-supplied irrigation (2.64%). However, although Central Italy presents the lowest overall irrigation demands, the Islands register the minimum values of unit irrigation requirements.

Overall, the data highlight a marked geographical gradient in the irrigation water requirements of vineyards, attributable to differences in the distribution of vineyard areas, regional climatic conditions, and irrigation practices adopted across the different supply systems.

3.1. *Advanced irrigation techniques and Regulated Deficit Irrigation (RDI)*

Regulated Deficit Irrigation (RDI) in viticulture is an increasingly studied and applied agronomic strategy aimed at efficiently managing water resources while improving grape quality. Although grapevines are well adapted to the hot and dry Mediterranean climates, water scarcity remains a major constraints limiting photosynthesis, growth, and productivity. The effects of water stress do not manifest immediately but gradually impact plant development, varying according to the phenological stage at which they occur. For example, early-season water deficits can reduce shoot growth or cause flower abortion, whereas excessive irrigation during the final ripening stages may lower grape quality by reducing sugar content. Therefore, the use of RDI techniques rely on targeted irrigation interventions limited to specific phases of the vine's life cycle, aiming to induce moderate stress that enhances grape quality without penalizing productivity. Effective application requires precise monitoring of the plant's water status. While soil-based indicators may be imprecise, physiological indicators such as stem water potential and stomatal conductance provide more direct and reliable information. Modern viticulture, especially in warm-arid contexts and under changing climate conditions, increasingly focuses on strategic water use. Deficit irrigation techniques not only help save water resources but also enhance the qualitative potential of grapes by increasing phenolic compound concentrations and improving the organoleptic characteristics of wine. In this context, every irrigation decision – from timing to water volume supplied – must be carefully calibrated based on vineyard-specifics and climatic conditions, aiming to improve water use efficiency and making viticulture more sustainable and resilient. Several studies have demonstrated that RDI, combined with monitoring systems (e.g., soil moisture sensors, water balance predictive models), can reduce water use by 25% to 40% while maintaining stable yields (Ahmadpour *et al.*, 2022; Ortuani *et al.*, 2019). However, its effectiveness is strongly influenced by local factors (climate, cultivar, soil type) and requires attentive and flexible agronomic management. In the Italian context, the adoption of RDI techniques remains limited but growing, especially in areas with restricted water access or where high-quality objectives are pursued (Losciale *et al.*, 2024). Although original experimental data were not analyzed in this study, the discussion is based on evidence from scientific literature. The following section presents the main results from reviewed studies and described indices, focusing on agronomic and economic aspects of viticulture and irrigation management, with the goal of deriving concluding remarks and practical insights.

4. Conclusions and limitation of the work

Italian viticulture is currently in a critical phase of adaptation because of increasing climatic pressures, such as reduced rainfall, increased evapotranspiration, and more frequent extreme weather events. These factors are transforming the water cycle in many wine-growing regions, making irrigation increasingly necessary, even in areas that have traditionally not relied on it. Non-irrigated vineyards are particularly vulnerable to prolonged droughts and heatwaves, which have a negative impact on yield, grape quality and the physiological health of the plant. In this context, accurate and detailed knowledge of the water requirements of vines is fundamental to developing sustainable irrigation strategies and effective public policies for water resources management. Quantifying irrigation requirements precisely allows water application to be optimised, reducing waste and preserving increasingly scarce water resources. This information is also essential for implementing innovative agronomic practices such as RDI, which involves strategically modulating the water supply during sensitive phenological stages to improve water use efficiency and fruit quality.

Spatial analyses based on ISTAT and SIGRIAN datasets confirm the expansion of irrigated areas by 27.1% between 2010 and 2020. This growth underscores the increasing dependence of the Italian wine sector on water resources, particularly in north-eastern regions where advanced infrastructure enables the intensive use of irrigation technologies. However, this evolution also highlights the increasing territorial heterogeneity of irrigation needs, driven by climatic, pedological, varietal and infrastructural factors.

In this context, an analytical and methodological approach capable of operating at a fine territorial scale – i.e. at the level of the winegrowing micro-region – is indispensable. Collecting climatic data (e.g. precipitation, temperature, evapotranspiration, extreme events), soil data (e.g. available water capacity, texture, useful depth), agronomic data (e.g. varieties, rootstocks, phenology, cultivation practices) and socio-economic data (e.g. costs, regulatory constraints, access to technology) enables the creation of water balance models tailored to specific environments and vineyards.

These models, fed by field sensors, localised meteorological data and digital technologies such as GIS, DSS and IoT, enable more accurate estimates of actual water requirements and facilitate the implementation of adaptive, localised irrigation strategies.

The study therefore proposes an innovative methodology for estimating the irrigation requirements of vines based on harmonised national-scale datasets. Data uniformity is a key development in this study, overcoming one of the main issues encountered in large-scale irrigation planning so far: information heterogeneity and fragmentation. Integrating data from official sources (ISTAT, SIGRIAN) provides a consistent national-level overview, useful for supporting policymakers in defining targeted, science-based strategies. These strategies align with the United Nations Sustainable Development Goals (SDG 6: Clean Water and Sanitation; SDG 13: Climate Action) and the priorities of the 2023-2027 Common Agricultural Policy, which promotes climate adaptation, resource efficiency, and the adoption of innovative technologies. However, the use of data still faces significant limitations in terms of availability, quality, and consistency of sources. The European Water Resilience Strategy aims to overcome these challenges by promoting a more robust and integrated information base, which is essential for accurate planning and sustainable management of water resources across all sectors.

In this context, the European Water Resilience Strategy 2025 further emphasizes the importance of a 'Water Efficiency First' approach. The aim is to improve water use efficiency by 10% by 2030 through integrated governance, innovation, and research measures (EU, 2025). Aligned with these objectives, the Common Agricultural Policy (CAP) financially supports investments in precision irrigation technologies and digital agriculture, encouraging the adoption of smart systems that combine production efficiency and environmental sustainability.

The proposed methodological framework can therefore provide a solid scientific basis for guiding these investments and promoting the development of Irrigation Advisory Services (IAS), which can provide farmers with localised, data-driven recommendations. However, limitations remain, particularly with regard to the spatial resolution of the available data. Aggregating information by macro-areas (e.g. ISTAT ecoregions) inevitably results in a loss of local detail and risks overlooking important intra-territorial differences in actual irrigation demand.

In conclusion, accurately assessing the water needs of vines and adopting targeted, evidence-based irrigation techniques is crucial for ensuring the sustainability, quality and resilience of Italian viticulture. Only a scientifically based, technologically advanced, and territorially differentiated approach can effectively address the challenges posed by climate change and the growing scarcity of water resources.

Conflicts of interest

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References

Ahmadpour, A., Farhadi Bansouleh, B., & Azari, A. (2022). Proposing a combined method for the estimation of spatial and temporal variation of crop water productivity under deficit irrigation scenarios based on the AquaCrop model. *Applied Water Science*, *12*(7), 154. Doi: 10.1007/s13201-022-01666-8.

Alba, V., Russi, A., Caputo, A. R., & Gentilesco, G. (2024). Climate Change and Viticulture in Italy: Historical Trends and Future Scenarios. *Atmosphere*, *15*(8), 885. Doi: 10.3390/atmos15080885.

Altobelli, F., Marta, A. D., Heinen, M., Jacobs, C., Giampietri, E., Mancini, M., Cimino, O., Trestini, S., Kranendonk, R., Chanzy, A., Debolini, M., Courault, D., Kanecka-Geszke, E., Kasperska-Wolowicz, W., Blanco-Velázquez, F. J., Anaya-Romero, M., De Witt, M., de Clercq, W., Espejo, A. D., … Giudice, T. Del. (2021). Irrigation Advisory Services: Farmers preferences and willingness to pay for innovation. *Outlook on Agriculture*, *50*(3), 277-285. Doi: 10.1177/00307270211002848.

Andrenelli, M. C., Pellegrini, S., Becagli, C., Orlandini, A., Perria, R., Storchi, P., & Vignozzi, N. (2025). A Monthly Water Balance Model for Vineyard Planning and Inter-Row Management. *Agronomy*, *15*(1), 233. Doi: 10.3390/agronomy15010233.

Baltazar, M., Castro, I., & Gonçalves, B. (2025). Adaptation to Climate Change in Viticulture: The Role of Varietal Selection – A Review. *Plants*, *14*(1), 104. Doi: 10.3390/plants14010104.

Bentivoglio, D., Chiaraluce, G., & Finco, A. (2024). Water stress as a critical issue for Mediterranean viticulture: economic evidence from the Montepulciano d'Abruzzo PDO grape based on a case study in central Italy. *Wine Economics and Policy*, *13*(1), 141-150. Doi: 10.36253/wep-15257.

Busschaert, L., de Roos, S., Thiery, W., Raes, D., & De Lannoy, G. J. M. (2022). Net irrigation requirement under different climate scenarios using AquaCrop over Europe. *Hydrology and Earth System Sciences*, *26*(14), 3731-3752. Doi: 10.5194/hess-26-3731-2022.

Copernicus Climate Change Service (2025). *Global Climate Highlights 2024. Copernicus Climate Change Service*. -- https://climate.copernicus.eu/global-climate-highlights-2024.

CREA-PB (2020). *SIGRIAN, Sistema informativo nazionale per la gestione delle risorse idriche in agricoltura-Presentazione degli interventi su base SIGRIAN.*

Di Vita, G., Califano, G., Raimondo, M., Spina, D., Hamam, M., D'Amico, M., & Caracciolo, F. (2024). From Roots to Leaves: Understanding Consumer Acceptance in Implementing Climate-Resilient Strategies in Viticulture. *Australian Journal of Grape and Wine Research*, 1-10. Doi: 10.1155/2024/8118128.

Díaz, M., Concepción, E. D., Morales, M. B., Alonso, J. C., Azcárate, F. M., Bartomeus, I., Bota, G., Brotons, L., García, D., Giralt, D., Gutiérrez, J. E., López-Bao, J. V., Mañosa, S., Milla, R., Miñarro, M., Navarro, A., Olea, P. P., Palacín, C., Peco, B., … Velado-Alonso, E. (2021). Environmental Objectives of Spanish Agriculture: Scientific Guidelines for their Effective Implementation under the Common Agricultural Policy 2023-2030. *Ardeola*, *68*(2). Doi: 10.13157/arla.68.2.2021.fo1.

Esposito, P., Giuffrida, P., & Lungarotti, C. (2024). Gli effetti del cambiamento climatico sulla viticoltura: Esposito, Giuffrida e Lungarotti ne parlano sul Financial Times. *Confagricoltura*. -- https://www.confagricoltura.it/ita/area-stampa/dicono-di-noi/gli-effetti-del-cambiamento-climatico-sulla-viticoltura-esposito-giuffrida-e-lungarotti-ne-parlano-sul-financial-times.

European Water Resilience Strategy (2025).

Galeotti, S., Cacchiarelli, L., Rossi, E. S., Henke, R., & Zucaro, R. (2025). The Role of Italian Local Agencies for Water Management in the Mitigation of and Adaptation to Climate Change: Stated Preference Methods for Future Sustainable Strategies. *Sustainability*, *17*(8), 3360. Doi: 10.3390/su17083360.

Gerbi, V., & De Paolis, C. (2025). The effects of climate change on wine composition and winemaking processes. *Italian Journal of Food Science*, *37*(1), 246-260. Doi: 10.15586/ijfs.v37i1.2775.

Guadagno, E. (2012). I Consorzi di tutela e gli organi di certificazione dei vini di qualità. *Diritto e giurisprudenza agraria, alimentare e dell'ambiente*, *2*, 131-136.

ISTAT (2010). *6° Censimento Generale dell'Agricoltura – Anno 2020*. -- https://www.istat.it/statistiche-per-temi/censimenti/agricoltura/.

ISTAT (2020). *7° Censimento Generale dell'Agricoltura – Anno 2020*. -- https://www.istat.it/it/censimenti/agricoltura.

Kyriakopoulos, G. L., Sebos, I., Triantafyllou, E., Stamopoulos, D., & Dimas, P. (2023). Benefits and Synergies in Addressing Climate Change via the Implementation of the Common Agricultural Policy in Greece. *Applied Sciences*, *13*(4), 2216. Doi: 10.3390/app13042216.

Losciale, R., Day, J. C., Rasheed, M. A., & Heron, S. F. (2024). The vulnerability of World Heritage seagrass habitats to climate change. *Global Change Biology*, *30*(1). Doi: 10.1111/gcb.17113.

Magno, R. (2025, July 11). *Situazione Siccità, bollettino giugno 2025*. Drought Central-Osservatorio Siccità. -- https://droughtcentral.it/

Manganiello, V., Banterle, A., Canali, G., Gios, G., Branca, G., Galeotti, S., De Filippis, F., & Zucaro, R. (2022). Economic characterization of irrigated and livestock farms in The Po River Basin District. *Economia Agro-Alimentare*, *23*(3), 1-24. Doi: 10.3280/ecag2021oa12773.

Ortuani, B., Facchi, A., Mayer, A., Bianchi, D., Bianchi, A., & Brancadoro, L. (2019). Assessing the Effectiveness of Variable-Rate Drip Irrigation on Water Use Efficiency in a Vineyard in Northern Italy. *Water*, *11*(10), 1964. Doi: 10.3390/w11101964.

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