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Research article

Every cloud has a silver lining: Winners and losers from droughts

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ABSTRACT

The paper aims to analyse the socioeconomic impacts of the 2022 drought on Italian agriculture, focusing on its distributive effects either from the sectoral or the regional perspective. A methodology based on consumer surplus theory was adopted. This allowed for identifying and quantifying impacts in terms of overall well-being for two different stakeholders: farmers and consumers. The change in well-being recorded for each is determined by the sum of two significant effects: the "price effect" and the "quantity effect". Interestingly, while consumers suffered economic losses due to the 2022 drought ("losers"), most farmers, thanks to the "price" effect, not only did not lose but gained ("winners"). Demand elasticity is affecting the patterns of distribution. Our results challenge a simplistic understanding of the economic effects of droughts and have numerous implications for policy.

1. Introduction

Many studies predict a significant intensification of droughts in the next decades due to climate change and other factors. Europe represents a hot spot for climatic variations; as a result, an increased frequency of extreme events, such as droughts, hailstorms, and floods, is expected to occur (EEA, 2024).

These phenomena will likely affect agriculture with the highest severity, calling for immediate action to improve resilience and mitigate the effects (Ding et al., 2011; Stahl et al., 2016; Gunst et al., 2015; FAO, 2015). However, socioeconomic impacts are more difficult to predict since they originate from a complex combination of factors that arise both from the "supply" side (meteorological, hydrological and infrastructural) and from the "demand" side, such as the structure of the agricultural sector, cropping choices etc. (Logar and van den Bergh, 2013; Mendelsohn and Dinar, 2009). Understanding the regional and sectoral distribution of these impacts is fundamental for identifying and calibrating policy actions.

The present article analyses the impact of droughts on agriculture, focusing on Northern Italy during the 2022 event, which was unprecedented in severity and duration in historical records.

The Italian case is of utmost significance and, to some extent, paradigmatic. Northern Italy is relatively water-rich due to the temperate climate and widespread mountain chains; mountain chains provide for regular spring and summer flows thanks to snow melting and the natural storage capacity in groundwater and lakes (Rossi and Benedini, 2021). Over time, this geographical pattern has favored the development of a water-intensive economy, taking advantage of easy and cheap access to water resources (Vaglietti et al., 2021).

This is especially the case in the agricultural sector, where a widespread irrigation system started being created early in the Middle Ages (Dono et al., 2019); nowadays, more than 2 million hectares are irrigated (Zucaro, 2014), contributing to an estimated 83% of agricultural GDP (Vignani et al., 2016). This fortunate situation has a drawback in that reliance on cheap water has discouraged investments in more water-efficient and resilient irrigation techniques while incentivising farmers to choose water-intensive high-value crops (Vaglietti et al., 2021). These features exacerbate the impact of an unexpected drought that happens to strike an unprepared system.

The Italian agri-food sector specialises in niche products of high quality, often characterised by territorial trademarks, such as protected geographical indications (PGI). This is particularly true for flagship productions such as cheese or cured meats, whose production is often statutorily tied to raw materials produced locally, such as animal feed.

Our research methodology is based on the social welfare theory of producers' and consumers' surplus. This approach is standard in public economics and has been extensively used for drought assessment, yet mainly concerning urban water supply (Woo, 1994; Garcia-Valinas, 2006; Grafton and Ward, 2008; Martin-Ortega and Markandya, 2009). In the case of agriculture, it has been applied in previous work

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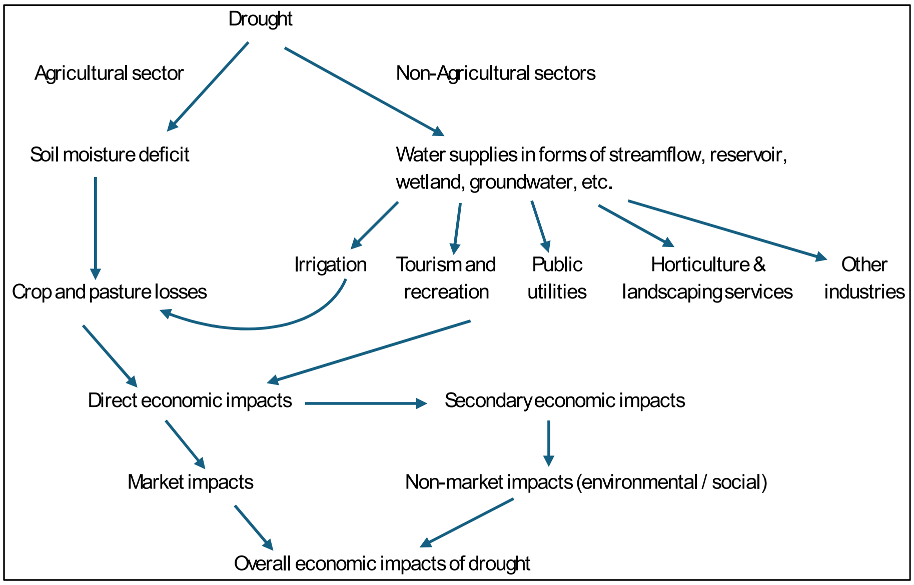

Fig. 1. Graphic representation of the total economic impacts resulting from a drought situation. Source: Authors' elaboration.

conducted by the authors (Massarutto and de Carli, 2009; Musolino et al., 2017, 2018). The present study extends the methodology of the latter studies to analyse a more recent drought event in 2022. It focuses on changes in social welfare for two distinct groups (consumers and farmers) and analyses them with greater detail regarding crops and affected territories.

The novelty of the study stems from various reasons.

In the first place, it provides new empirical evidence using a method with few precedent applications, except the ones quoted above; with respect to more sophisticated methods applied in other academic studies, it has the advantage of being applicable with a far lower data requirement.

Second, the analysis is conducted here at a more localized geographical scale. This level of detail allows us to understand the implications for the local agricultural system with greater precision.

Third, we have considered a more detailed set of crops, which enables us to understand the effects on more specific markets more precisely and formulate more precise interpretations of the results.

In particular, demand elasticity appears to play a decisive role. The higher the elasticity, the lower the effect on price is expected. Therefore, it is essential to investigate the reasons that can make prices more or less responsive to quantity variations in the short and long term before we can identify those who receive the highest damage.

The article is structured as follows. Section 2 illustrates the methodological framework and the underlying economic theories, particularly the consumer surplus theory. Section 3 provides some background information about the 2022 event, highlighting its exceptional magnitude. Section 4 describes the case study area under examination, its economic structure, and its vulnerability to drought events. Section 5 presents the analysis results regarding the distributional effects of drought events on the agricultural sector in the reference area. Section 6 discusses the policy implications of the findings, and section 7 draws some concluding remarks.

2. Related literature

Understanding droughts' economic impact is difficult (Mendelsohn and Dinar, 2009).

A "meteorological" drought (lower rainfall than usual) is not immediately reflected by water shortage since this also depends on local hydrology; moreover, "hydrological" water shortage can be compensated by man-made water management systems. Furthermore, water demand can be more or less elastic, also depending on the alternative solutions available in the short and long run. Therefore, these elements should be combined to produce socially relevant outcomes (Tallaksen and van Lanen, 2004).

Second, there are different effects to consider. Ding et al. (2011) distinguish direct impacts (lower yields, product losses), indirect impacts (e.g., those in the economic sectors that are economically integrated with primary production, such as the food industry, retail sector, agricultural inputs), and socio-environmental effects commonly known as non-market losses. The latter include the disruption of crop growth stages, reduction in the size and quality of yields, increased risk of diseases and pests, decreased biodiversity, and changes in crop rotation practices (e.g., damages to ecosystems and landscape).

Impacts can be limited to the short term. Still, they can also have long-term repercussions, for example because of permanent damage to roots and to tree cultivation or because farmers learn from experience and reduce the surface area allocated to water-intensive crops (Hanel et al., 2018).

However, the impacts differ significantly depending on the availability of irrigation. While the effects on rainfed agriculture typically concern yields, irrigated agriculture will likely escape this but, in return, will likely face higher costs, e.g., for pumping or extraordinary manpower (Dono et al., 2016).

Fig. 1 below provides a brief summary of the total economic impacts arising from a drought situation. Drought affects both the agricultural and non-agricultural sectors, causing a chain reaction of economic consequences. In agriculture, soil moisture deficits lead to crop and pasture losses, disrupting irrigation and causing direct economic impacts. Non-agricultural sectors, reliant on water supplies from streams, reservoirs, and groundwater, experience disruptions in tourism, public utilities, horticulture, and other industries. These direct impacts on the agricultural and non-agricultural sectors generate secondary economic effects (i.e. indirect induced effects), including market losses and environmental/social costs, which together contribute to the overall economic burden of drought on society.

Farmers may attempt to compensate for diminished yields and recover the additional costs by increasing prices. Depending on whether and how much this is feasible, farmers can reduce losses and even convert them into profit.

Various methodologies are used to estimate the economic impact of drought on agriculture, each with specific advantages and applications (Ding et al., 2011).

The most diffused studies are based on expected or actual crop yield variations, such as the Aquacrop model developed by FAO (Salman et al., 2021). This methodology allows a more immediate quantification of immediate effects. Mysiak et al. (2013) provided an application to the Italian case, with a special focus on our case-study area.

However, these models often fail to consider either the effects on prices or the subsequent reaction of farmers to adapt and, therefore, may overestimate the consequences on farmers and overlook the possible gains to some of them (Logar and van den Bergh, 2013; Mendelsohn and Dinar, 2009; Kraemer, 2007).

Econometric studies have been applied to the ex-post evaluation of the overall impact of droughts on value added and sectoral GDP (Zaveri, 2023). Other studies highlight that having access to irrigation is key in determining whether farmers will ultimately lose or benefit from unusually dry conditions (Dono et al., 2016).

Input-output (I-O) and Computable General Equilibrium (CGE) models seek to capture the indirect effects that spread from agriculture to the rest of the economy; being based on parameters deducted from previous periods, these approaches may fail to estimate correctly the impact of disruptive events. Ziolkowska (2016) used an I-O model to quantify the economic impacts of the 2011 Texas drought, finding losses of $7.62 billion.

Computable General Equilibrium (CGE) models have been used to analyse drought impacts in Mediterranean countries, showing how markets react to rising agricultural commodity prices (García-León et al., 2021; Mysiak et al., 2013).

Fewer studies focus on distributive effects. Massarutto and de Carli (2009) used a welfare economic framework to quantify the impacts of drought in the Po River basin area, allowing for a comprehensive understanding of the consequences of drought events and facilitating the formulation of appropriate policies to mitigate corresponding risks. Musolino et al. (2018) adopted the same approach to compare three different countries (Portugal, Spain, and Italy), finding diverse impact patterns depending on demand elasticity.

3. Background information

3.1. The hottest and driest year in recent history

The rather unprecedented 2022 crisis is well documented by official statistics (Ispra, 2023a, 2023b). This has been the hottest year in Italy since 1961, with an average anomaly of about +1.23 °C compared to the previous thirty years 1991–2020 (Fig. 2).

The atmospheric blocking that affected the peninsula throughout the year, coupled with relatively low precipitation values, contributed to the persistence of exceptionally high thermal values either in spring or early summer. Northern regions were the most affected.

Negative thermal and rainfall anomalies started being recorded in January and February and once again in the spring season. The number of consecutive days without rain reached values above 40 up to 80 – a very uncommon case in the North.

Spring and summer outflow was further affected by the lower-than-average snow coverage (Fig. 3). Once more, this phenomenon was particularly acute in the Alps, where the Snow Water Equivalent (SWE) index recorded a 66% deficit in February, the lowest in the last two decades. The rapid melting of the snow cover determined a lower-than-usual replenishment of the subalpine lakes and artificial reservoirs (in Lombardy alone, storage decreased by 30% (Ispra, 2023b).

As a result, available water resources at the national level diminished by 51,5% with respect to the average 1961–2022 period and 49,8% with respect to the last 30 years; in the Po basin, reductions are respectively 66,6% and 65,9% (Fig. 4).

Once again, the most significant effects were on water reserves: in the Alpine region, glacial reserves decreased by about a third, and the Po River flow reached exceptionally low values (Fig. 6), causing a rise in the salt wedge in the delta.

This combination of phenomena is regarded as exceptional when compared to historical records; however, they could represent the "new normal" case due to climate change. Since 2000, Northern Italy has already experienced 3 "exceptional" droughts, even though the 2022 case remains the most acute in meteorological and hydrological terms.

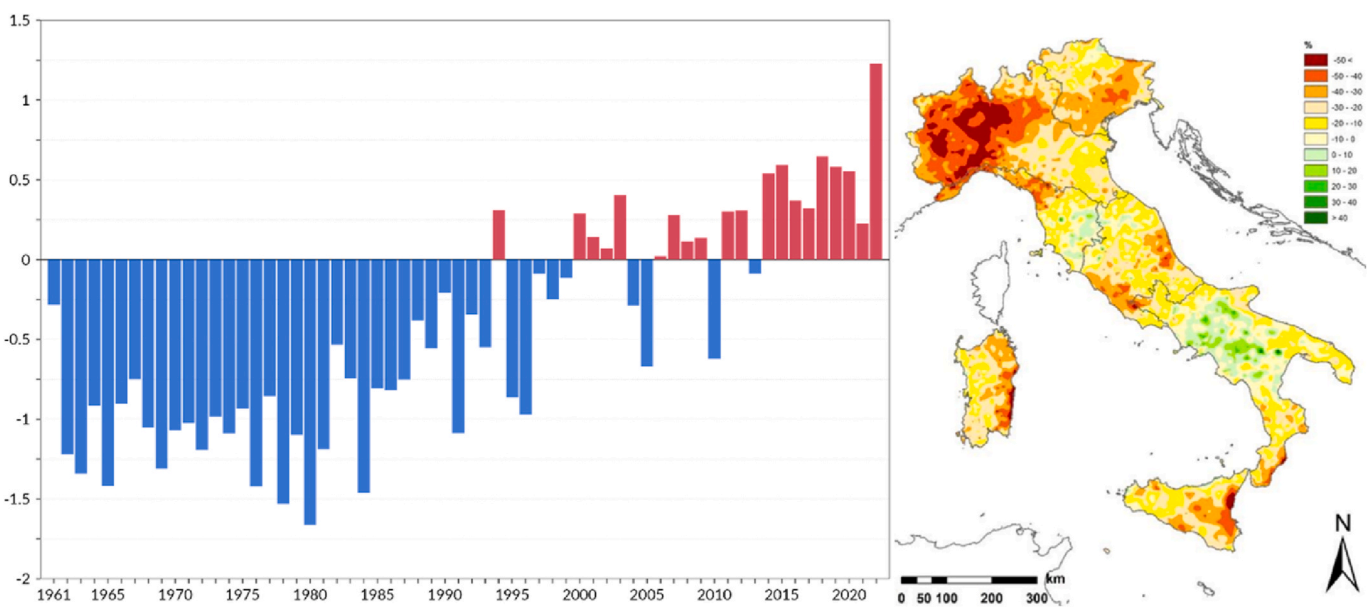

Fig. 2. Series of anomalies in average temperature (left) and cumulative precipitation (right), compared to normal climatological values from 1991 to 2020.

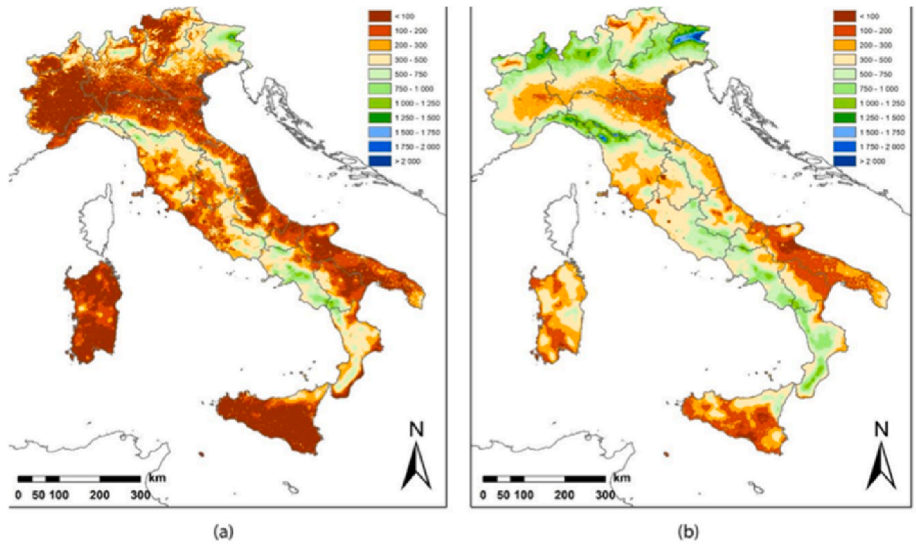

Fig. 3. Freshwater availability in 2022 (left) compared with the 1961–2022 average (right). Source: ISPRA, 2022a (left); ISPRA, 2022b (center and right).

3.2. Case study area: the Po river basin

The Po River Basin covers a broad geographic region extending across Northern Italy (ADPO, 2018). It represents the largest floodplain in Italy and receives its water from the Western and Central sections of the Southern Alpine chain as well as from the Northern side of the Northern Apennines. Its territory is highly diverse in terms of geography, demographics, and socioeconomics. It includes the totality of Aosta Valley, Piedmont, Lombardy, and Emilia-Romagna regions, plus small fragments of Veneto, Tuscany, Liguria, and Trentino (Fig. 5).

The Po is the longest river in Italy (approximately 652 km) and branches extensively across the territory with its 141 tributaries. It is also the largest watershed in Italy, with an average annual outflow of 1.506 m^3/s.

It covers less than 25% of the Italian territory and one-third of its population, has an average density of 348 inhabitants/km^2, and totalizes more than 40% of the Italian GDP.

Among the most relevant industries, agro-food represents an excellence, with 41% of the Italian value added.

The primary sector contributes for 35% of the total Italian

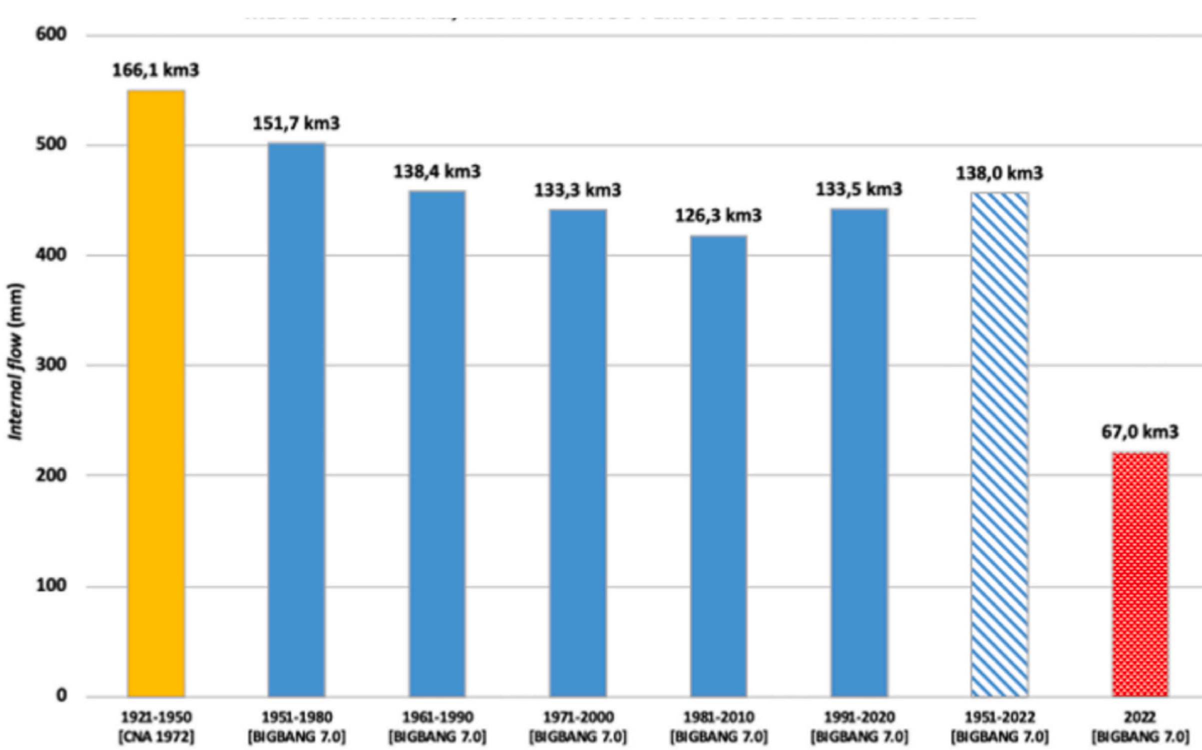

Fig. 4. Freshwater availability in 2022, compared with 30-year averages. Source: Ispra (2023b).

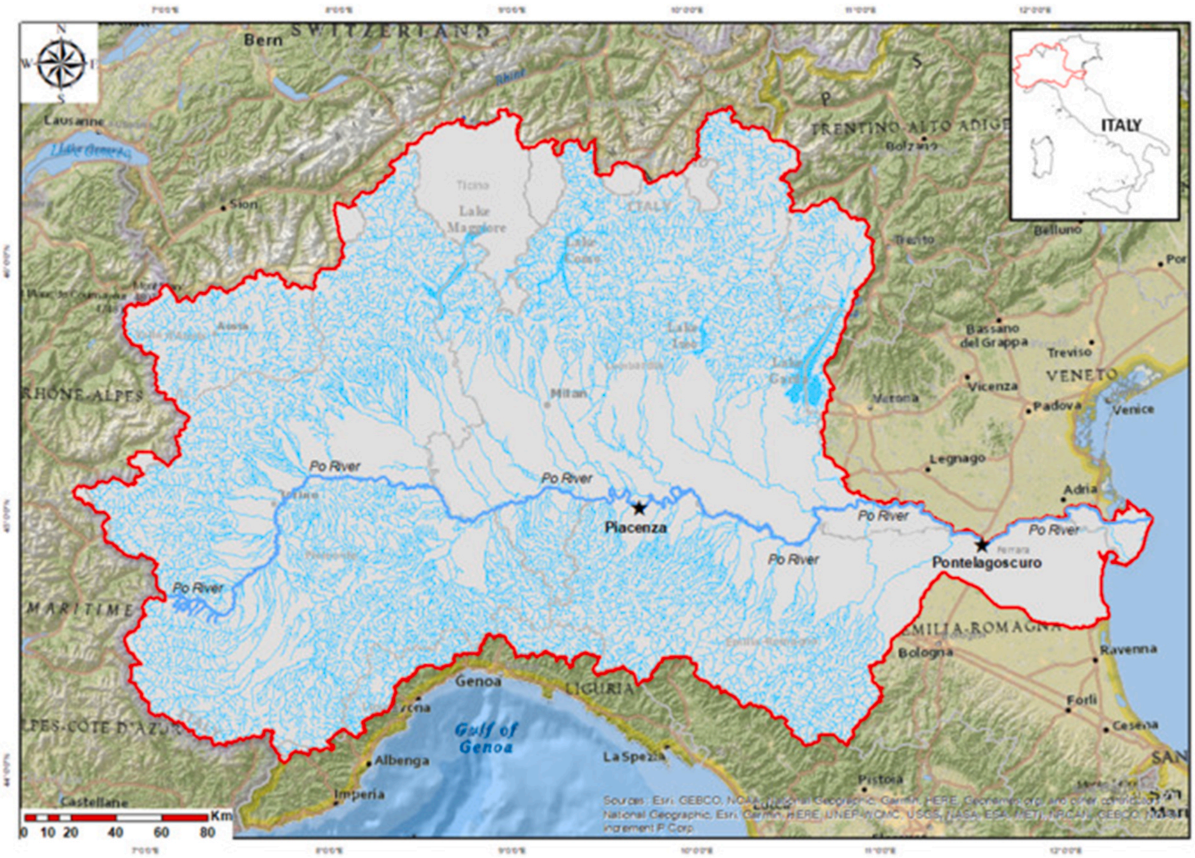

Fig. 5. Administrative boundaries of the Po River Basin. Source: ADPO, 2018.

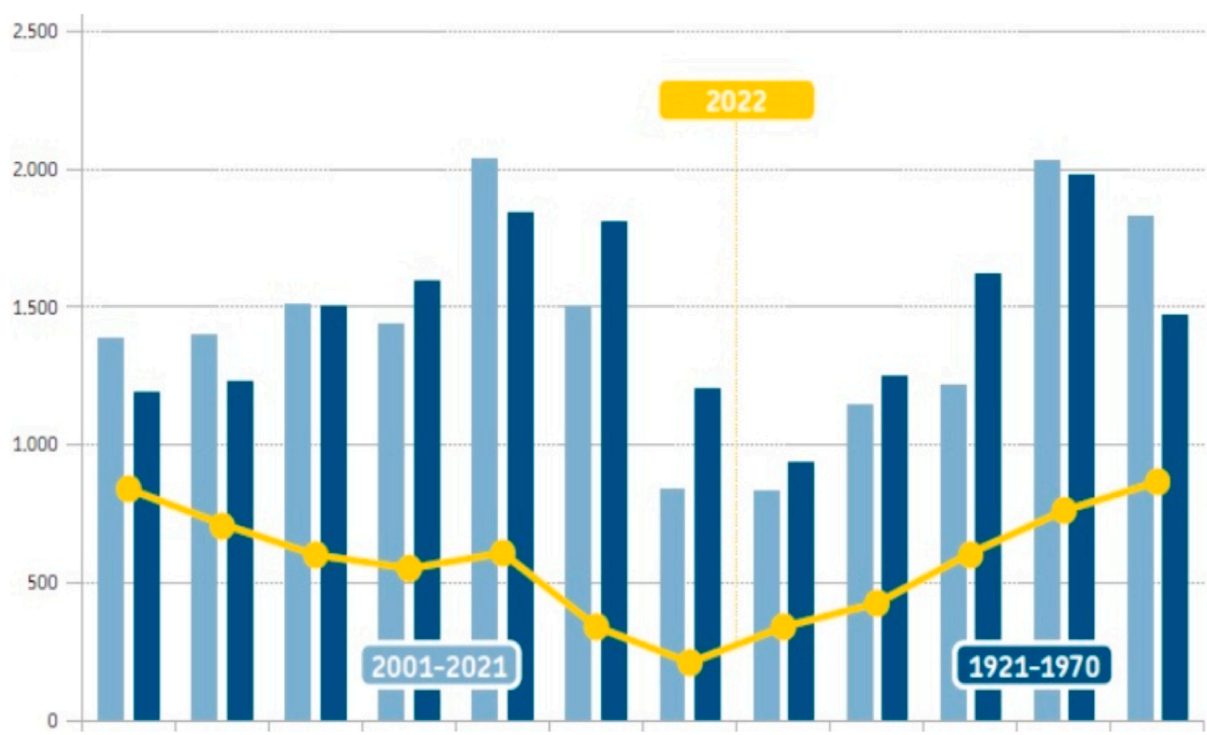

Fig. 6. Monthly average outflows on the Po at the mouth: 2001–2021 (light blue), 1921–1970 (dark blue) and 2022 (yellow line). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
– Breakdown of used agricultural surface in Piedmont, Aosta Valley, Lombardy, and Emilia-Romagna (2021).

	Arable		Plant farming		Kitchen gardens		Pasture and meadows		Total used surface
	He	%	he	%	he	%	he	%	**he**
Piedmont	574.904	61,06%	103.675	11,01%	697	0,07%	262.236	27,85%	941.512
Aosta Valley	2.124	3,45%	736	1,19%	26	0,04%	58.721	95,31%	61.608
Lombardy	759.385	75,41%	43.604	4,33%	329	0,03%	203.667	20,23%	1.006.985
Emilia-R.	863.473	82,64%	118.192	11,31%	709	0,07%	62.450	5,98%	1.044.824
TOTAL	2.199.886	72,01%	266.207	8,71%	1.761	0,06%	587.074	19,22%	3.054.929

Source: authors' elaboration on data from ISTAT

Table 2
– Irrigable and irrigated surface in Piedmont, Aosta Valley, Lombardy, and Emilia-Romagna (2021).

	Total used surface	Surface equipped for irrigation		Irrigated surface		
	he	he	%	He	% of TUS	% of equipped
Piedmont	941.512	430.156	45,7%	360.031	38,2%	83,7%
Aosta Valley	61.608	19.688	32,0%	17.536	28,5%	89,1%
Lombardy	1.006.985	679.949	67,5%	570.835	56,7%	84,0%
Emilia-R.	1.044.824	596.381	57,1%	291.090	27,9%	48,8%
TOTAL	3.054.929	1.726.174	56,5%	1.239.492	40,6%	

Source: authors' elaboration on data from ISTAT

Table 3
– Breakdown of irrigated surface and total irrigation water demand (Piedmont, Aosta Valley, Lombardy, province of Rovigo, Emilia-Romagna, 2010).

	Piedmont		Aosta Valley		Lombardy		Veneto (Rovigo)		Emilia-Romagna		Total Po district	
	Irrigated surface	Volume of water used	Irrigated surface	Volume of water used	Irrigated surface	Volume of water used	Irrigated surface	Volume of water used	Irrigated surface	Volume of water used	Irrigated surface	Volume of water used
	%	%	%	%	%	%	%	%	%	%	%	%
ARABLE CROPS	70,4%	85,7%	0,4%	0,8%	63,6%	84,3%	76,5%	83,3%	33,4%	42,3%	59,0%	80,2%
Maize	30,4%	17,5%	0,1%	0,4%	36,2%	17,4%	45,6%	46,8%	17,0%	19,2%	30,4%	18,0%
Rice	33,2%	65,4%	0,0%	0,2%	18,3%	63,8%	5,9%	18,8%	3,2%	12,3%	19,0%	58,2%
Other cereals	5,1%	2,0%	0,0%	0,0%	5,2%	1,6%	9,4%	6,0%	4,0%	3,0%	5,0%	1,9%
Dry legumes	0,5%	0,2%	0,0%	0,0%	0,6%	0,2%	0,9%	0,5%	0,5%	0,4%	0,5%	0,2%
Potato	0,2%	0,1%	0,2%	0,1%	0,1%	0,0%	0,4%	0,3%	1,8%	1,6%	0,5%	0,2%
Sugar beet	0,1%	0,1%	0,0%	0,0%	0,8%	0,2%	4,7%	3,2%	3,5%	2,7%	1,2%	0,5%
Other arable	0,9%	0,4%	0,1%	0,0%	2,4%	0,9%	9,7%	7,7%	3,4%	3,1%	2,4%	1,1%
INDUSTRIAL CROPS	0,3%	0,1%	0,0%	0,0%	0,4%	0,1%	1,3%	0,7%	0,3%	0,3%	0,4%	0,1%
Rapeseed	0,2%	0,0%	0,0%	0,0%	0,3%	0,0%	0,8%	0,3%	0,1%	0,0%	0,2%	0,0%
Sunflower	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,3%	0,3%	0,1%	0,2%	0,1%	0,0%
Other industrial crops	0,0%	0,0%	0,0%	0,0%	0,1%	0,0%	0,2%	0,1%	0,1%	0,1%	0,1%	0,0%
FODDER CROPS	21,5%	10,7%	96,6%	97,5%	31,3%	14,0%	6,7%	5,6%	22,2%	22,6%	26,7%	14,0%
Green maize	5,0%	2,4%	0,0%	0,0%	16,3%	6,9%	3,2%	2,6%	4,3%	4,1%	10,0%	5,4%
Permanent grassland	10,3%	5,1%	96,6%	97,5%	6,1%	2,8%	0,1%	0,1%	3,6%	3,8%	7,8%	3,6%
Other fodder crops	6,2%	3,3%	0,0%	0,0%	8,9%	4,2%	3,4%	2,9%	14,4%	14,7%	9,0%	5,0%
PLANT FARMING	5,9%	2,9%	2,9%	1,7%	2,2%	1,0%	6,5%	6,1%	26,6%	21,7%	8,4%	3,6%
Vineyards	0,0%	0,0%	1,5%	0,4%	0,4%	0,1%	0,1%	0,0%	7,1%	3,1%	1,7%	0,4%
Fruit trees	4,8%	2,1%	1,3%	1,1%	0,6%	0,2%	5,7%	5,1%	18,9%	18,1%	5,8%	2,6%
Olive	0,1%	0,0%	0,0%	0,1%	0,0%	0,0%	0,0%	0,0%	0,1%	0,0%	0,1%	0,0%
Citrus	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Tree farming	0,7%	0,6%	0,0%	0,0%	0,7%	0,5%	0,4%	0,7%	0,1%	0,2%	0,5%	0,5%
Plant nurseries	0,2%	0,1%	0,0%	0,0%	0,5%	0,2%	0,3%	0,3%	0,3%	0,3%	0,4%	0,2%
HORTICULTURE	2,0%	0,7%	0,1%	0,0%	2,5%	0,7%	9,0%	4,3%	17,5%	13,1%	5,5%	2,0%
TOTAL - ALL CROPS	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%

Source: Authors' elaboration on data from Istat

agricultural production, 55% arising in 5 specific provinces only. For a more precise breakdown, we focus on the 4 Regions that are entirely comprehended in the Po district; these represent 90% of the total surface of the river basin.

Total Useable agricultural land (3,8 million hectares) covers 40% of the whole territory, yet only 79% of it is actually cultivated, with a continuous downward trend leading to a progressive concentration (ADPO, 2018). The cultivated surface is dominated by arable land (72%), plant farming (8,7%) and pasture (19,2%) (Table 1).

Nearly half of arable land is occupied by cereals (with maize representing 40% of this total). Vineyards occupy half of the surface devoted to plant farming; in the remaining half, Piedmont has a remarkable

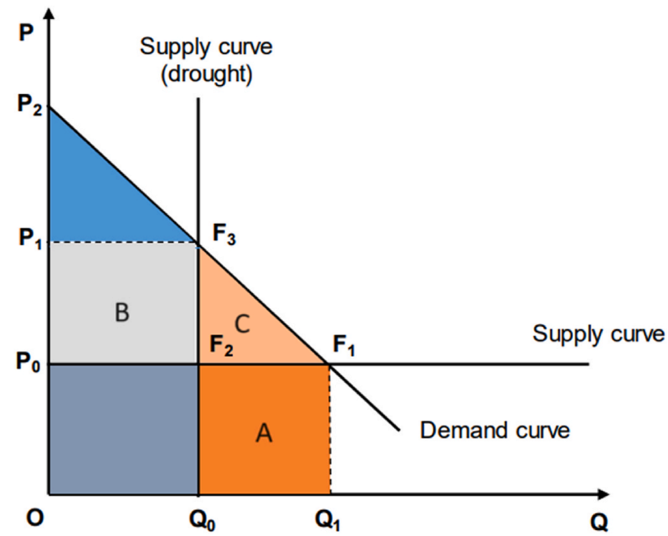

Fig. 7. Short-term effects on agricultural production following a drought event.

surface dedicated to hazelnuts, while apples and pears are the most relevant in the other regions. Despite the relatively small surface devoted, plant farming and other greenhouse products offer a high value-added.

Nearly 25% of used agricultural land is connected to agro-food value chains that produce certified-quality products (Adua, 2014).

Irrigation is widely diffused. More than 1,7 million hectares are equipped for irrigation (Table 2), which accounts for 56% of the total cultivated surface, with a total consumption of 7.4 billion m^3. As shown in Table 3, maize and rice alone account for 50% of irrigated surface and 76% of water consumption. Fodder crops account for another 27% of irrigated surface and 14% of water consumption. Regional differences are also evident, with a higher share of plant farming in Emilia-Romagna.

From a hydrological perspective, the water supply for agricultural activities is usually high and ensured by various natural sources (rainfall, ponds, rivers, groundwater, and Alpine lakes).

Collective irrigation is supplied by about 50 "irrigation boards", namely landowners' associations with public status. These boards operate a vast network of canals and serve approximately 70% of demand. The remaining 30% is managed directly by farmers using different complementary sources such as groundwater, small lakes and ponds.

We can identify three main zones with relatively homogeneous features, which roughly correspond to the regional territory. Firstly, Lombardy has numerous available water sources and an effective storage system provided by natural lakes and upstream reservoirs specially built for hydropower production. Thanks to these resources and storage capacity, Lombardy can ensure proper water management to meet diverse needs. The second zone is represented by Piedmont and Aosta Valley, which have similar sources but relatively lower storage capacity. This can pose a challenge since limited storage capacity may impact water availability during specific periods or under particular needs. Finally, Emilia-Romagna is the most adept at artificial resource storage, compensating for the relatively lower raw water sources. Thanks to well-developed storage infrastructure, Emilia-Romagna can effectively accumulate and manage water for various purposes, ensuring greater water security. Considering these aspects is crucial in the planning and managing water resources to ensure sustainable use and equitable distribution of water among different zones and for various needs.

Water resources planning is the responsibility of Regions. They are legally obliged to coordinate themselves within the Po River District Authority (ADPO). This institution provides technical support and centralized data management and is the competent body under the EU Water Framework Directive. However, it lacks adequate personnel endowment and financial resources; therefore, it can exert more soft power and need to rely on Regions for implementation, each having its own regulatory framework. This situation leads to a lack of uniformity in practices and can even generate tensions in case water resources are insufficient to meet all needs. The absence of a coherent framework can make it challenging to coordinate resource allocation, monitor, and allocate water for agricultural purposes fairly and efficiently. Nonetheless, even with this limited power, the ADPO has effectively coordinated the emergencies that took place during the recent drought events in 2002 and 2005–2006, managing to prevent the worst outcomes (Massarutto and Musolino, 2021; Musolino et al., 2019).

As discussed in par. 3.1, subalpine basins like the Po are seriously affected by climate change, which makes it likely that similar events will become more frequent in the future, calling for more incisive

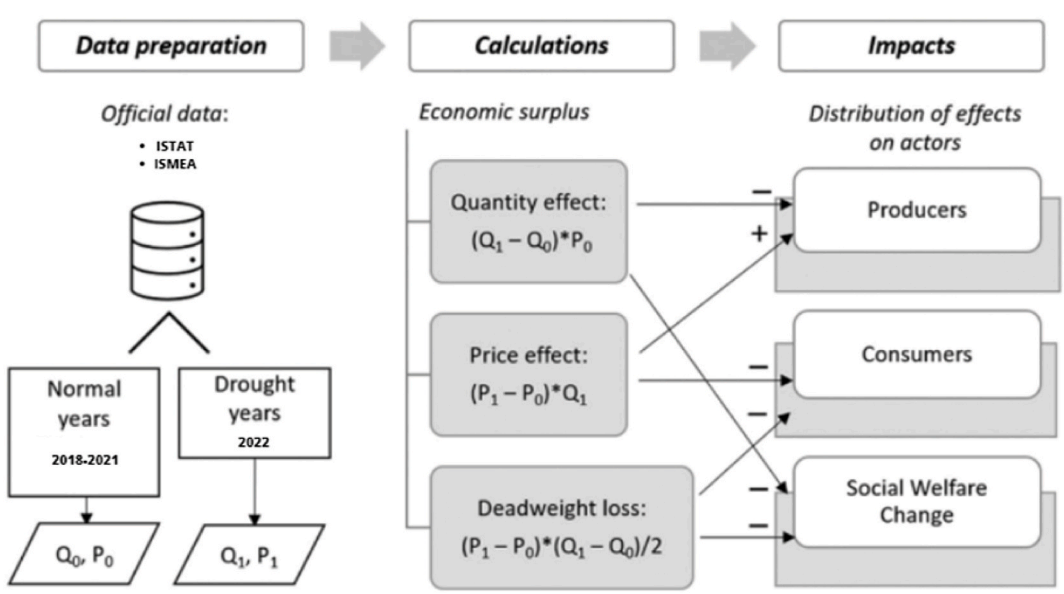

Fig. 8. Methodology followed to assess the impacts of drought on economic surplus.

coordination of adaptation measures. Modelling work conducted for the National Plan of Adaptation to Climate Change predicts a general decrease in the flow of the Po River and a simultaneous increase in water demand for agriculture due to temperature increase causing higher evapotranspiration (MASE, 2023)

3.3. Data and basic assumptions

The estimation of impacts on agricultural production in the Po River Basin following the 2022 drought event was conducted by analyzing historical series of annual productions of agricultural crops. The data supporting the study were provided by the National Institute of Statistics (ISTAT) and cover four different groups of crops (cereals, industrial crops, fruits, and vegetables) in the nine regions involved in the Po River Basin. The limitation resulting from the categorization of crops into only four groups might initially seem characterized by a reduction in information. Nevertheless, it is crucial to recognize that this targeted selection is indispensable for obtaining synthetic results. Additionally, the identified groups collectively represent 82% of the total production distributed over 40% of the cultivated land. This focus strategy aims to ensure a balance between synthesis and representativeness, enabling a comprehensive and exhaustive analysis of the main dynamics in the agricultural landscape within the Po River Basin.

Changes in agricultural production (ΔQi) were estimated as the difference between the production in year i, the year of drought event registration, and the average production of the four preceding years. Similarly, changes in prices (ΔPi) were estimated as the difference between the prices of agricultural products recorded in year i and the average prices of the same products in the four preceding years. To accurately determine the value associated with each analyzed agricultural product, tariff data collected by the Institute of Services for the Agricultural and Food Market (ISMEA) were used.

4. Methods and materials

4.1. Consumer surplus theory

The methodology applied in the present study is based on consumers' surplus theory. It adapts the approach used by the authors to analyse previous drought events in the same area and in other European regions (Massarutto and de Carli, 2009; Musolino et al., 2018).

Table 4
Percentage change in prices and quantities of agricultural goods between 2022 and the average of the previous four years.

	ΔP_{2022}	ΔQ_{2022}
Cereals	80.10%	−14.8%
Industrial Crops	56.20%	−12.3%
Fruits	3.40%	33.8%
Vegetables	11.30%	−7.7%

Source: Authors' elaboration based on ISMEA data

The method measures social well-being by comparing the maximum value individuals would be willing to pay for a good or service to their actual price to obtain it. This difference is referred to as consumer surplus.

These effects are depicted in Fig. 7 below, where a generic agricultural product's market price (P) is placed on the vertical axis, and its quantity (Q) is placed on the horizontal axis. The demand function D represents the maximum "willingness to pay" of consumers for any additional amount. At the same time, the supply curve illustrates the minimum price asked by the producer to supply it, corresponding to its additional cost. We assume here for simplicity that the supply curve is horizontal (i.e., producers can accommodate demand sustaining a constant cost until the production capacity is wholly exhausted) and that it becomes vertical (perfectly inelastic) after that point. This assumption makes the calculation easier but could be easily removed to obtain a more realistic representation of real-world cases. We also assume that the production cost is fixed, i.e., farmers have already sustained it in the previous periods and are now only waiting to harvest. The price p represents therefore their economic margin.

In a situation of average water availability, the equilibrium point is located at F_1, at the intersection between the demand and supply curves. The area between points $P_2P_0F_1$ is identified as the total consumer surplus, representing the difference between what consumers are willing to pay for Q_1 of the agricultural product – the area between points $P_2OQ_1F_1$ – and what consumers actually pay – the area between points $P_0OQ_1F_1$.

Suppose now that because of an unexpected drought, the production drops to Q_0. The supply curve is shifted to the left. The excess demand, resulting from reduced supply, causes an increase in the price. In the new market equilibrium, F_3, consumers' surplus is reduced to the area $P_2P_1F_3$, significantly smaller than the previous $P_2P_0F_1$.

The area $P_1P_0F_1F_3$ identifies their total loss. This is the combined

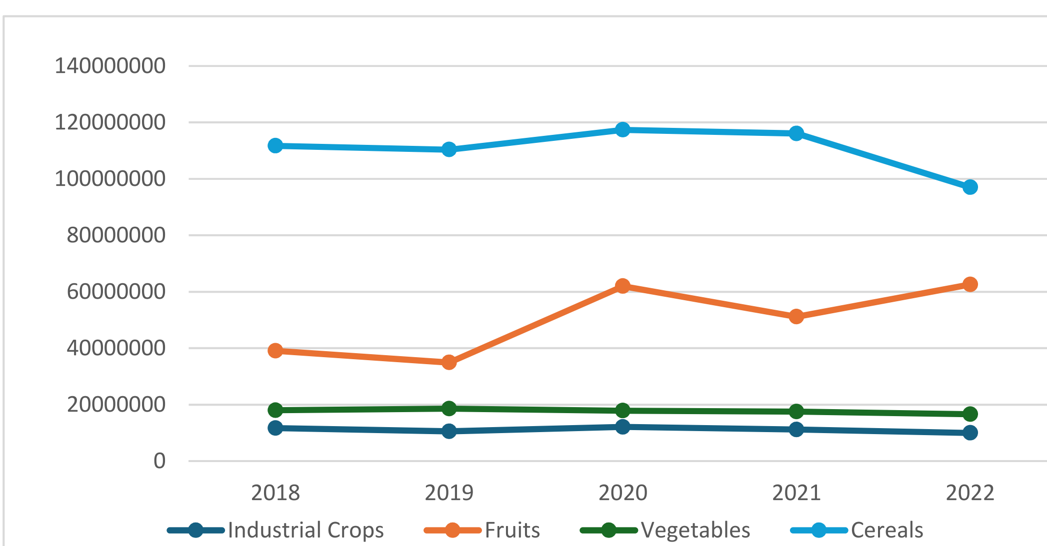

Fig. 9. Annual production of the main crops between 2018 and 2022 (100 kg). Source: Authors' elaboration based on ISTAT data.

Table 5
Impacts of the 2022 drought (thousand euros per year).

	Quantity Effect	Price Effect	Deadweight Loss	TOT	Loser	Winner
PRODUCERS	−4936	27113	–	22177		x
CONSUMERS	–	−27113	−1987	−29100	x	
Social Welfare Impacts	−4936	–	−1987	−6923		

Source: Authors' elaboration based on ISTAT and ISMEA data.

Table 6
Impacts of the 2022 drought on producers and consumers in the Po Basin by type of agricultural product (thousand euros per year).

		Quantity Effect	Price Effect	Deadweight Loss	TOT	Losers	Winners
PRODUCERS	Cereals	−4705.7	25636.5		20930.8		x
	Industrial Crops	−268.1	1469.4		1201.3		x
	Fruits	39.8	4.4		44.2		x
	Vegetables	−2.1	2.4		0.3		x
	TOT	−4936.1	27112.7		22176.6		x
CONSUMERS	Cereals		−25636.5	−1897.4	−27533.9	x	
	Industrial Crops		−1469.4	−90.2	−1559.7	x	
	Fruits		−4.4	0.7	−3.7	x	
	Vegetables		−2.4	−0.1	−2.4	x	
	TOT		−27112.7	−1986.9	−29099.6	x	

Source: Authors' elaborations based on ISTAT and ISMEA data.

result of a negative price effect (area B) – they pay a higher price for Q_0 - and the so-called deadweight loss (area C) – they cannot buy the additional quantity Q_0Q_1 anymore.

Let's examine the new situation from the perspective of producers. They will now be unable to sell Q_0Q_1 and will lose the corresponding margin (quantity effect, $P_0\Delta Q$, that is area A). However, they will now sell the remaining quantity at a higher price, increasing their margin (price effect, $Q_0\Delta P$, i.e., area B). From a societal viewpoint, area B is a clearing entry (a loss for consumers and a gain for farmers).

The final outcome for consumers is surely negative (-B -C), while that for farmers is ambiguous (B-A) and depends on the relative magnitude of B and A.

It is straightforward to notice that the relative size of the price and quantity effects for farmers, and similarly that of the "deadweight loss" C ($\Delta P\Delta Q/2$) depend on the slope of the demand curve, i.e., on its elasticity. With an elastic demand, ΔQ will be bigger and ΔP lower, and vice-versa. Therefore, with an inelastic demand, a decrease in production will be accompanied by a proportionally higher price increase. Elasticity depends ultimately on the possibility of replacing the missing local production with other products (e.g., imports).

4.2. Practical application to the case under analysis

This simple model can be easily applied since the data for estimating both effects is readily available. It is sufficient to gather information about quantity variations and prices, both recorded by official market observatories.

The data acquisition process, their analysis, and the subsequent evaluation of impacts can be summarized in a diagram, as shown in Fig. 8 below.

The data sources from ISTAT and ISMEA used in this analysis are institutional and operate under the direct supervision of the Italian Government. Both institutions collect and analyse data rigorously and impartially, using well-established methodologies that are validated through review processes. Specifically, they must adhere to European and international standards, such as those from Eurostat, the UN, and the IMF, to ensure data consistency and comparability. To ensure that the variations observed are due to the drought and not to other confounding factors, we have considered a 4-year average from previous years.

However, like any statistical source, they are subject to potential biases or limitations.

The first limitation arises from data granularity. Both ISTAT and ISMEA collect data for all the regions under analysis, but they do so in different ways. ISTAT collects the quantity data on the regional (NUTS-2) and provincial (NUTS-3) scales, while ISMEA gathers price data from "plazas." A "plaza" is a marketplace where agricultural data is collected and shared. Each region may have one or more "plazas," but not every province is represented by a "plaza". Therefore, we needed to refer to the regional scale to reconcile both datasets, calculating an average regional price.

This limitation is more severe when market data are not fully homogeneous. Recorded data cannot always refer to each specific commodity, and even when it does (e.g., for apples or grapes), we cannot be sure that it concerns lots of the same quality. To maintain clarity in the analysis, we decided to aggregate and focus on four major categories of agricultural products, for which price and quantity data were readily available from the two datasets used in this research (ISTAT and ISMEA).

Second, we assume that products are sold directly from farmers to final consumers. This is usually not the case since trading can concern intermediate goods (e.g., tomatoes for the canning industry), or involve wholesalers and retailers. It is unclear whether the price increase of the primary product, whose yield has been affected by the drought, will be passed through to final prices or absorbed by the following stages of the value chain. For a clearer picture, one should refer to retail prices that are much more difficult to collect.

Third, we have assumed that the production cost has been already sustained and the drought only affects the quantity harvested. However, farmers may have to sustain extra costs because of the drought. In this case, the price increase would transfer extra costs and therefore might not reflect higher profits. This might be a significant limitation, as without information on production costs, it might become difficult to determine whether the increase in selling prices is solely a consequence of the diminished production due to the drought or it is driven by rising production costs or if it.

5. Results: Total effects of drought and distributional effects on farmers and consumers

5.1. Distributional effects on farmers and consumers

The first stage in conducting a comprehensive analysis of the distributional effects of drought involves identifying the entities that benefit from it and those that suffer losses, commonly referred to as 'winners' and 'losers.' For this purpose, the consumer surplus theory has been employed to calculate three fundamental effects: the quantity effect, the price effect, and the deadweight loss, concerning the drought that affected the Po River basin region in 2022.

Fig. 9 and Table 4 first show respectively the trend of the yearly production of the main crops between 2018 and 2022, and the percentage change in quantities and prices between 2022 and the average of the previous four years. Thus, the application of consumer surplus theory follows, revealing that the net winners of the drought situation are producers (Table 5).[1]

The positive economic result achieved by them is the combined outcome of a negative quantity effect, stemming from the reduced production of many crops, and a very favorable price effect, originating from the increase in market prices for individual products. Quantitatively, following the drought in 2022, agricultural producers gained approximately 22.177 million euros. In contrast, consumers, who were identified as losers following the drought events, experienced a drastic reduction in their well-being. Indeed, not only were they negatively impacted by a reduction in the quantities produced, but they also had to endure significant price increases, resulting in an overall loss of about 29.100 million euros. In summary, the overall impact on social welfare was dramatically negative, with a total loss amounting to approximately 6.923 million euros, figures that far exceed what was observed in previous drought events.

5.2. Distributional effects by type of agricultural product

The analysis presented in the previous section provides a general overview of the effects of drought on key actors in the agricultural sector in the Po River basin area. In the following section, we intend to examine and quantify in more detail the economic impacts on different categories of crops cultivated in the area under study. This level of detail is particularly important as it implicitly allows us to discern which segment of producers has benefited the most from the drought situation.

Table 7
Crucial demographic, geographic, and agricultural data for the main regions of the Po Basin.

	LOMBARDY	PIEDMONT	EMILIA-ROMAGNA
Population	9.950.742	4.240.736	4.426.929
Territory (Km^2)	23.863	25.387	22.123
Plainland (Km^2)	11.222	6.714	10.570
Hillside (Km^2)	9.673	7.698	5.993
Mountain (Km^2)	2.964	10.987	5.560
SAU (h)	1.006.984	941.511	1.044.824
N. of agricultural enterprises	46.893	51.703	53.753
Young agricoltural enterprises	16,75%	16,99%	11,45%
Main Crops	1. Cereals (77,7 %) 2. Vegetables (11,9 %) 3. IC (6,6 %) 4. Fruits (3,8 %)	1. Cereals (76,3 %) 2. Fruits (17,3 %) 3. Vegetables (4,4 %) 4. IC (2,0 %)	1. Cereals (51 %) 2. Fruits (28,1 %) 3. Vegetables (16,2%) 4. IC (4,7 %)

Source: Authors' elaborations based on ISTAT data.

As mentioned earlier, the analysis was conducted considering the four main categories of agricultural products in the area under examination: cereals, industrial crops, vegetables, and fruits.

As clearly visible in Table 6, the effects of drought on different types of agricultural products vary significantly. From the perspective of producers, cereals are undoubtedly the category of crops that has contributed the most to the creation of wealth (EUR 20,930 million). In particular, the decrease in the quantities produced of wheat, maize, and rice was more than compensated by an increase in prices compared to the previous four years. Table 6 highlights how, thanks to a reduction of about 15% in production and a prices increase by about 80% (or 5.3 times as much), there was a quantity effect of Eur −4706 million and a price effect of Eur 25,636 million. Industrial crops also saw an increase in selling prices compared to the last 4 years (+56.2%), allowing for the partial negative quantity effect (Eur −0,268 million) to be offset by a price effect of Eur 1469 million. Regarding fruits, producers enjoyed a double positive effect: contrary to what happened with other crops, the quantities produced increased significantly compared to the previous period (+33.8%), while prices only experienced a moderate increase (+3.4%). As for the last case considered, vegetables, the overall net positive impact is due to a positive price effect that managed to fully offset the negative effect resulting from the decrease in quantities produced.

In the described situation, fruit producers are the absolute winners as they can count on the double positive effect benefiting the entire category of producers. Following them are cereal and industrial crop producers, whose incidence of the negative effect on the total is essentially identical but with a significant difference in their absolute values: despite similar dynamics, cereal producers can enjoy an increase in well-being of EUR 20,930 million, while industrial crop producers have an increase in well-being of only EUR 1201 million. However, both groups incur high losses in terms of quantities produced, meaning that some of the specialized producers in these crops have lost all or part of their harvest and have not been able to benefit from the positive price effect. In the last position are vegetable producers, who, although they can be considered net winners, experience a total well-being increase of only EUR 0.3 million, a value significantly lower than the other categories.

While fruit producers seem to benefit the most from the positive price and quantity effects, it's important to take a more nuanced view of their performance during drought conditions. Despite the overall gains in well-being, fruit producers probably faced significant cost pressures, which tempered their relative success compared to other agricultural categories.

O the one hand, they were very resilient, due to many factors. First, the use of efficient irrigation systems, such as drip irrigation, frequent in fruit production, likely allowed for controlled and sustainable water usage, ensuring that fruit trees received the necessary water even when other crops struggled. Second, as perennial crops, fruit trees have deep root systems that access water from lower soil levels, making them naturally more resilient to drought conditions. Third, specialized cultivation practices, including improved soil management and the use of drought-resistant varieties, further enabled fruit producers to maintain or even slightly increase their output, unlike other crop categories. Additionally, the strong demand for fruits, coupled with rising prices during the drought, helped mitigate the impact of any minor reductions in production.

However, on the other hand, they likely experienced a rise in production costs due to increased irrigation needs and higher input costs (such as water and fertilizers). This eroded their profit margins. Therefore, although rising selling prices helped offset some of these costs, the overall economic outcome for fruit producers was not as clear-cut as initially perceived. The combination of higher input costs and price increases highlights the complex nature of their performance during the drought.

Thus, while fruit producers were able to withstand the drought relatively well, calling them "absolute winners" may be an

[1] It should be noted that not all producers have been affected in the same way. Indeed, it is assumed that some of them have suffered serious damages, such as the loss of the entire harvest.

Table 8
Impacts on producers in the three main regions of the Po Basin.

	Lombardy	Losers	Winners	Piedmont	Losers	Winners	Emilia-Romagna	Losers	Winners
Cereals	4241.0		X	4513.5		x	4263.3		x
Industrial Crops	546.0		x	160.4		x	530.6		x
Vegetables	0.5		x	−1.0	x		0.3		x
Fruits	–			−0.3	x		5.7		x
TOTAL	4787.5		x	4672.7		x	4799.9		x

Source: Authors' elaborations based on ISTAT and ISMEA data.

Table 9
Changes in price and quantity of each product category, divided by production region.

	Lombardy		Piedmont		Emilia-Romagna	
	ΔP	ΔQ	ΔP	ΔQ	ΔP	ΔQ
Cereals	74.1%	−20.7%	71.9%	−12.7%	72.2%	−9.0%
Industrial Crops	65.0%	11.5%	57.5%	−0.5%	75.3%	−2.6%
Vegetables	16.3%	2.7%	11.0%	−54.1%	20.9%	−10.0%
Fruits	–	48.0%	8.8%	−7.8%	7.1%	53.4%

Source: Authors' elaborations based on ISTAT and ISMEA data.

Table 10
Changes in Producers and Consumers welfare (rice production).

	Changes in welfare for Farmers	Changes in welfare for Consumers
Piedmont	1.640	−1.918
Lombardy	543	−1.420
Emilia-Romagna	47	−92

Source: Authors' elaborations based on ISTAT and ISMEA data.

Table 11
Comparison of drought impacts on the agricultural sector in the years 2003, 2005/2007, and 2022 (in million euros).

2003	Quantity Effect	Price Effect	Deadweight Loss	TOT
PRODUCERS	−551	1257		706
CONSUMERS		−1257	−41	−1298
Social Welfare Impacts	−551		−41	−592
2005/2007	Quantity Effect	Price Effect	Deadweight Loss	TOT
PRODUCERS	−578	778		200
CONSUMERS		−778	−41	−819
Social Welfare Impacts	−578		−41	−619
2022	Quantity Effect	Price Effect	Deadweight Loss	TOT
PRODUCERS	−4936	27113		22177
CONSUMERS		−27113	−1987	−29100
Social Welfare Impacts	−4936		−1987	−6923

Source: Authors' elaboration based on ISTAT and ISMEA data (and on data from Musolino et al., 2018).

overstatement. The high production costs likely tempered their overall gains. Further research into the long-term sustainability of these practices and the true economic impact on fruit producers would be beneficial to provide a more nuanced understanding of how they fared during drought conditions.

Regarding consumers, identifying who has lost or gained from the drought is seemingly simple. In general, all consumer groups had to bear a reduction in well-being, but, consistent with what was observed in the analysis of producers, those who suffered the greatest impacts were cereal consumers (with a total loss amounting to EUR 27,534 million). Following them are industrial crop consumers, with a loss of EUR 1560 million, and fruit and vegetable consumers, who incur a much lower loss - EUR 3.7 million and EUR 2.4 million, respectively.

A minor clarification should be done for rice, which stands out as a unique case within the category of cereals. Over the past 4 years, its production has significantly decreased by 17%, in contrast to its price which has exponentially increased by 83%. These variations exceed the averages recorded for the entire cereal category, thus explaining much of the welfare losses and gains for the various actors involved in this agricultural product category. Specifically, rice has contributed to an increase in welfare for agricultural producers amounting to €2.881 billion, while resulting in an overall loss of €4.228 billion for consumers.

After analyzing the varying impacts of drought on different types of agricultural products, it becomes clear that price dynamics also play a crucial role in shaping these distributional effects. The ability of certain products to withstand price surges better than others highlights another important aspect of market resilience during drought periods. The significant price increases for various crops, despite reduced production, can be attributed to several key underlying factors. One of the primary drivers is the inelasticity of demand for essential agricultural goods. Many of these crops, particularly staple foods, have few viable substitutes, meaning that consumers continue to demand them even when prices rise. This low degree of substitutability—where consumers cannot easily switch to alternatives—pushes prices upward when production decreases. This is especially evident for local products certified under IGP, DOP, or DOCG, which are inserted into regulated food chains and must adhere to strict production standards. These products have very low substitutability due to their unique characteristics, such as geographic origin and traditional production methods, making them even more in demand during shortages.

Additionally, crops tied to local food preferences and marketed as such tend to experience stronger demand even during supply shortages, further driving prices. Products with IGP, DOP, or DOCG certification are particularly affected, as their marketing often emphasizes their exclusivity and quality, sustaining demand despite price hikes.

Another important factor is the role of marketing, particularly for crops positioned as high-value or niche products, such as organic or locally sourced foods. Marketing can sustain demand even in the face of higher prices, particularly for consumers willing to pay a premium for these qualities.

Although not analyzed in detail, the rising cost of production during droughts or adverse weather conditions likely exacerbates price surges. Higher input costs, including water, labor, and fertilizers, directly contribute to higher final product prices. As production becomes more expensive, producers pass on these costs to consumers, which is especially noticeable in periods of low supply.

In the short term, these price increases are sustainable as long as the underlying demand for these crops remains inelastic and the products cannot be easily substituted. However, in the long term, the sustainability of such price surges may come into question. Over time, consumers may adjust their preferences or shift to more affordable alternatives, especially if high prices persist. Additionally, technological advancements in crop production or supply chain efficiency could eventually stabilize or reduce prices as production recovers and costs decrease.

Table 12
Comparison of the impacts of drought on the involved stakeholders and main crops in the years 2003, 2005/2007, and 2022 (in million euros).

2003		Quantity Effect	Price Effect	Deadweight Loss	TOT
PRODUCERS	Cereals	−422.9	685.7		262.8
	Industrial Crops	42.4	47.3		89.7
	Fruits	−125.0	91.0		−34.0
	Vegetables	−45.8	433.3		387.5
	TOT	−551.3	1257.3		706.0
CONSUMERS	Cereals		−685.7	9.4	−676.3
	Industrial Crops		−47.3	−2.6	−49.9
	Fruits		−91.0	−19.1	−110.1
	Vegetables		−433.3	−28.6	−461.9
	TOT		−1257.3	−40.9	−1298.2
2005/2007		Quantity Effect	Price Effect	Deadweight Loss	TOT
PRODUCERS	Cereals	−454.8	526.7		71.9
	Industrial Crops	47.4	207.6		255.0
	Fruits	−127.7	32.1		−95.6
	Vegetables	−43.4	11.7		−31.7
	TOT	−578.5	778.1		199.6
CONSUMERS	Cereals		−526.7	−41.0	−567.7
	Industrial Crops		−207.6	2.0	−205.6
	Fruits		−32.1	−2.0	−34.1
	Vegetables		−11.7	0.0	−11.7
	TOT		−778.1	−41.0	−819.1
2022		Quantity Effect	Price Effect	Deadweight Loss	TOT
PRODUCERS	Cereals	−4705.7	25636.5		20930.8
	Industrial Crops	−268.1	1469.4		1201.3
	Fruits	39.8	4.4		44.2
	Vegetables	−2.1	2.4		0.3
	TOT	−4936.1	27112.7		22176.6
CONSUMERS	Cereals		−25636.5	−1897.4	−27533.9
	Industrial Crops		−1469.4	−90.2	−1559.7
	Fruits		−4.4	0.7	−3.7
	Vegetables		−2.4	−0.1	−2.4
	TOT		−27112.7	−1986.9	−29099.6

Source: Authors' elaboration based on ISTAT and ISMEA data.

Therefore, while current price surges are primarily driven by inelastic demand, limited substitutes, and higher production costs, their long-term sustainability depends on how these factors evolve and whether producers can maintain these high prices without significantly losing market share to alternative products or substitutes.

5.3. Distributional effects by geographical region

Within the analysis of phenomena related to drought, a crucial step consists of examining the distributional effects in relation to the three main regions of the Po Basin: Lombardy, Piedmont, and Emilia-Romagna. This exploration aims to provide a more detailed understanding of the specific socio-economic and agricultural dynamics in these regions, considering their relevance within the analyzed context.

Before proceeding with the analysis of distributional effects by region, it is essential to gain an in-depth view of the characteristics of each considered region. The following Table 7 provides crucial demographic, geographic, and agricultural data for each region, offering a clear perspective on the differences and similarities among them.

As shown in Table 8, in all three regions, producers concluded the drought period with significant gains in well-being, although the composition of these gains differs from one area to another.

Starting with Lombardy, the absolute winners are producers of industrial crops and vegetables. They benefit from the dual positive effect resulting from increased quantities produced and higher average selling prices compared to the previous period (Table 9). In absolute values, this translates into gains of 546 and 0.5 million euros, respectively. Even cereal producers, with a 74% increase in selling prices, can consider themselves winners. Overall, this category of producers has seen an increase in well-being of about 4241 million euros. Finally, regarding fruit producers, it is not possible to determine the direction and extent of the impacts as data on exchange prices for this commodity category are not available.

In Piedmont, there are no absolute winners, only partial winners. Indeed, while cereal and industrial crop producers can boast a favorable price effect that has granted an increase in well-being of 4513 and 160 million euros, respectively, both suffer a strong negative effect due to the decrease in quantities produced. On the contrary, fruit and vegetable producers are absolute losers: the price increase for these two commodity categories has not been sufficient to offset the reduction in quantities produced, resulting in a net loss of 1 and 0.3 million euros,

Table 13
Policy implication summery.

Policy Area	Measure	Key Action
Efficiency in resource use	Reallocation of water resources to high-value crops	Infrastructure investment (canal systems, storage tanks, pumping, control structures).
	Diversification of water sources	Develop alternative water sources through infrastructure investment and R&D on new technologies.
	Adoption of advanced irrigation techniques	Encourage the shift from traditional methods to efficient systems to save water and improve yields.
	Reduce water wastage and uneven resource management	Promote modern irrigation methods to prevent soil degradation and reduce operational costs.
Transition to Sustainable Agricultural Practices	Education and awareness for younger farmers	Promote digital technologies, training, and innovative practices among younger farmers.
	Education and support for older farmers	Address resistance to change through training and support for adopting new technologies.

respectively.

Finally, there is Emilia-Romagna, which has overall managed to generate the best result in terms of gained well-being. Among the various categories of producers, those specializing in fruit cultivation stand out: the economic benefit of 5.7 million euros is the direct result of a significant increase in quantities produced (+53%) and a marginal increase in selling prices (+7%). Producers in other commodity categories also emerge as winners, despite all experiencing a strong negative quantity effect.

Drawing upon the same line of reasoning as previously discussed regarding the impact of rice within the broader cereal category, we have also endeavored to assess its influence on the well-being of both producers and consumers in the three primary regions under scrutiny. Our analysis reveals that the most significant impacts, in terms of magnitude, are observed in Piedmont, with impacts unevenly distributed between producers and consumers. However, a notable case worth examining is Lombardy, where despite substantial gains for producers, consumers face a disproportionately high loss. This is primarily attributed to a significant fluctuation in product prices (Lombardy exhibits one of the highest price fluctuations recorded across Italy). Finally, in Emilia Romagna, welfare losses and gains are considerably lower, with a balanced distribution between producers and consumers compared to the other regions. The welfare losses and gains of producers and consumers have been depicted in Table 10 below.

In addition to the differences in crop performance, regional disparities within the Po River basin further amplify the uneven impact of drought on agricultural production. Regional variations within the Po River basin play a crucial role in the overall conclusions about the economic impacts of drought. As highlighted in paragraph 3.2, the regions of Piedmont, Lombardy, and Emilia Romagna benefit from the presence of the Po River and its tributaries, which ensure greater availability of water resources. However, the extent to which these regions can capitalize on these resources varies depending on their territorial conformation and water resource management capacity. Some regions are more resilient to drought due to better water availability or conservation practices, while other areas suffer more severe losses. These variations inevitably affect the overall conclusions, as some regions are better able to mitigate the effects of drought than others.

The crops within the Po River basin are divided into four main categories, each with different water needs. Fruit, vegetables, and some industrial crops (IC) require higher volumes of water compared to cereals, which cover a larger area but have a lower volumetric water consumption. In regions with better access to water resources, such as Lombardy and Emilia Romagna, high water-demand crops have experienced fewer losses, while other regions with fewer water resources have been more severely impacted by drought. This highlights the importance of considering regional variations when analyzing the impact of drought on different crop categories.

These regional variations, such as differentiated access to water resources and crop distribution, directly influence the overall economic results of drought. While drought has caused widespread losses in agricultural production within the Po River basin, the regions with better water resources have been able to better contain these losses, significantly influencing the study's findings. Specifically, regions with greater access to water have been able to maintain or even increase production in certain crop categories, mitigating the negative effects of drought and contributing to a more varied economic impact at the regional level.

5.4. The previous drought events: a diachronic comparison of the distributional effects

The analysis conducted so far highlights how, following a calamitous event like drought, some groups of actors incur losses while others reap benefits. This phenomenon contradicts a perspective that was widely supported until recent times. To provide a comprehensive exposure, we will now proceed with a comparison of the results obtained with what was identified by Musolino et al. (2018) in their previous investigation focused on drought episodes in the years 2003 and 2005/2007.

Referring to Table 11, notable similarities emerge in the results obtained during the three periods under consideration. In all cases, despite a decrease in the level of social well-being, leading to losses for the community, the constant advantageous position of the category of producers in the context of drought is noteworthy.

However, from the collected data, a clear evolution in the magnitude of the impacts resulting from drought on the involved parties emerges.

i. **Increase in total losses** – The total social loss has significantly increased in 2022 compared to previous periods, rising from 592 to 619 million euros in 2003 and 2005/2007 to 6923 million euros in 2022.
ii. **Significant variations in producer gains** – Despite producers registering gains in all three periods, there is a noticeable increase in well-being in 2022, with an advantage of 22,177 million euros, compared to 706 and 200 million in the two previous periods.
iii. **Increase in consumer losses** – On the other hand, consumers have suffered increasingly substantial losses during these periods. Their losses have risen from 1298 to 819 million euros in the first two periods to a remarkable 29,100 million euros in 2022. This suggests that consumers have become significantly more vulnerable to the economic effects of the drought.

Through the analysis of Table 12, it is possible to compare the distributive effects related to different agricultural products in the three considered drought periods. The following trends emerge from this analysis.

i. In 2003, producers generally experienced an increase in well-being, except for those specializing in fruit cultivation. The latter benefited from an increase in selling prices; however, this increase was not sufficient to compensate for the decrease in quantities produced. Cereal and vegetable producers reaped the greatest benefits from the drought in terms of increased well-being.
ii. In the 2005/2007 period, cereal and industrial crop producers were the most benefited in terms of increased well-being. In particular, the second group of producers enjoyed a positive effect on both quantities produced and selling prices. Fruit and vegetable producers, on the other hand, experienced a significant reduction in quantities produced, which was not adequately offset by price increases. This led to substantial differences compared to the previous drought period.
iii. As previously highlighted, in 2022, cereal producers experienced a considerable increase in well-being and contributed significantly to the total well-being of producers – about 94% of the total.

What unites consumers in all three periods considered is the fact that cereals are the product category that has contributed the most to their loss of well-being.These analyses underscore the heterogeneity of the effects of drought on producers and consumers, with significant variations between different periods and different categories of agricultural products. They also highlight the important role played by cereals in driving changes in well-being levels.

The strategic geographical position of the Po River basin, located at the foothills of the Alps and surrounded by a network of lakes and rivers, makes it a territory naturally abundant in water resources. During the winter months, the accumulation of water in lakes, reservoirs, and mountainous areas is generally able to meet the entire summer water demand. The system of rivers and canals distributed throughout the territory facilitates the transfer of water resources, ensuring a constant flow throughout the year, thus mitigating the negative effects of the

Mediterranean climate. This geographical configuration has over time favored the settlement and development of an economy heavily dependent on water resources, including agricultural activities. The availability of low-cost water has allowed agriculture to extend its activities beyond the production of high-value crops, prompting the sector to diversify its practices and expand the range of cultivated crops. This combination of circumstances, which has transformed the Po River basin into a strategically significant, highly developed, and economically autonomous area, now constitutes a set of factors capable of explaining both the absolute magnitude of the economic costs associated with the drought events, showed in this analysis, and the challenges of adaptation. To address the challenges posed by droughts, two categories of key measures can be identified: those aimed at improving efficiency in resource use and those focused on enhancing awareness of sustainable resource use. In the first category of measures, resource reallocation, diversification of supply sources, and optimization of irrigation techniques are included, while the second category encompasses all possible actions aimed at transitioning to more sustainable agricultural practices.

6. Policy implications: a discussion

The results of our analysis provide some food for thought, as well as relevant implications for upcoming policy strategies related to drought management (see also Table 13).

It emerged that drought is a climatic phenomenon that manifests indiscriminately and can even affect geographical areas rich in water resources. This is because water stress is not solely correlated with the absolute availability of water, but is affected by the extent of use and the elasticity of water demand itself.

6.1. Measures to improve efficiency in resource use

The reallocation of available water resources towards high-value crops is a fundamental element in reducing economic losses due to droughts. However, the possibility for farmers to flexibly redistribute resources towards high-value crops is an ambitious goal and can only be achieved in the presence of adequate infrastructure. These should include canal systems, storage tanks, pumping facilities, and control structures on the distribution network. It is crucial to emphasize that, despite the efforts already made by the government over the years, the current system of water distribution for irrigation purposes requires significant investments (estimated at around 12 billion euros nationally) to meet the best international standards.

The increasing scarcity of traditional water resources calls for an approach based on the diversification of water sources. This approach ensures an adequate water supply even during peak demand periods when traditional sources may prove insufficient. However, like the previous case, diversification also requires significant infrastructure investments and research and development to refine available technologies.

Despite the growing trend of adopting more efficient irrigation techniques, many farmers continue to use traditional systems such as flood, submersion, or sprinkler irrigation. While these systems work, they result in water wastage, uneven resource management, and faster soil degradation. The adoption of advanced techniques offers benefits for both farmers – including energy savings, reduced operational costs, and improved yields – and the environment – reducing water extraction, increasing sustainability, and lowering the risk of hydrogeological disasters.

6.2. Measures for transitioning to sustainable agricultural practices: raising education and awareness

For presenting these measures, it is imperative to provide a comprehensive preamble to explain the unequivocal relevance of education in the agricultural context. This preamble should outline the target audience for education and justify its crucial role.

Within the 7th General Agriculture Census, developed by the National Institute of Statistics (ISTAT), significant data emerge. We observe that farms managed by individuals under the age of 40 are characterized by greater use of digital technologies, a wider range of activities, and considerable competitiveness. However, these farms represent only 9.3% of the total number of farms, marking a decline from 2010 when they accounted for 11.5%.

In contrast, farms managed by individuals aged 44 and above constitute the vast majority, accounting for 86.5%. These farms, however, face a series of significant challenges, including gaps in the adoption of digital technologies and a lack of professional training. Similarly, these farms demonstrate resistance to innovation and reluctance to technological change. This resistance to change can have a negative impact on business productivity and environmental sustainability.

To address these obstacles, it is hoped that the government, at all administrative levels, will play a crucial role in promoting education among farmers. The educational process should aim to instill a full understanding of the benefits associated with the adoption of sustainable and efficient agricultural practices, both environmentally and economically. Concurrently, the incorporation of farmers into water resource governance serves as a means to enhance their awareness of the importance of sustainable agricultural practices.

In summary, this contribution emphasizes the fundamental centrality of education in the agricultural sector as a tool to overcome challenges related to the age of farmers and to promote the transition to more sustainable and digitally advanced agricultural practices. Emphasis is placed on the active involvement of the government in this transformative process.

7. Concluding remarks

Our study highlights that drought is not necessarily detrimental to the agricultural sector despite the considerable social impacts. While it is undeniable that the primary sector has been significantly and directly affected, it is also true that agricultural operators have rarely felt the related consequences, on aggregate at least. We cannot exclude that single farmers in specific locations have received a significant impact. For a more refined understanding of how the price and quantity effect have impacted, therefore, we would need to increase the granularity of the dataset.

An indirect proof that our intuition is fundamentally correct, however, comes from a parallel set of interviews we have made with agricultural insurance providers, showing no apparent increase in the reimbursements paid in 2022.

Perhaps more challenging is the other shortcoming of our methodology, namely the neglect of the possibility that farmers have sustained extra production costs because of the drought. In the lack of adequate data, we had to rely on direct interviews with farmers. Most interviews confirmed that some additional costs had been actually sustained (especially for energy and manpower), but when asked to quantify them, they were unable to provide credible figures. This issue deserves to be investigated by future research.

Another weak point of our analysis, as mentioned above, regards the simple structure of the value chain that we have considered. Adding a more realistic description of the supply chain is particularly important in the Italian case, whose specificity rests precisely in its specialization in high-quality products that require a sophisticated organization of downstream transactions. An analysis focused on specific case studies of high-quality value chains could add very interesting insights.

Concurrently, future investigations should deepen the analysis by considering individual crops involved. This approach would allow for a more detailed exploration of the effects on crops with lower added value compared to those with higher value, highlighting subtle nuances in economic implications.

The implications emerging from this research underline the need for further studies aimed at improving the accuracy and understanding of economic dynamics within the examined sector. This can be achieved through a more thorough review of basic assumptions, a better understanding of the value chain, and a more detailed consideration of specific crop categories. In conclusion, there is a suggestion to extend the same research and methodology to different geographical areas to acquire additional empirical evidence. It is crucial to emphasize that an increase in the number of studies conducted in this context could provide a more solid foundation for the development of effective processes and policies in addressing the effects of a phenomenon of relevance and current importance, such as droughts.

CRediT authorship contribution statement

Stefano Scarsini: Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis. **Dario Musolino:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Conceptualization. **Antonio Massarutto:** Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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