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An agrometeorological analysis of weather extremes supporting decisions for the agricultural policies in Italy

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Abstract. The future European Common Agricultural Policy foresees Strategic National Plans founded on recognised needs for intervention and indicators in order to select the more effective policy measures. The Strategic plans start from a "context analysis", describing the current-starting conditions. In support to the policy theme on climate change, the authors proposed a context analysis on the main agrometeorological variables and weather extreme events, both at national and subnational (NUTS1) level. This paper describes the methodological choices made and the results obtained, considering the contents required by the European Commission for the context analysis (agrometeorological indicators and an indicator of economic damages due to natural disasters). The data source chosen is ERA5, the climate reanalysis dataset produced within the Copernicus project. The study demonstrates the importance of cross-reading data on hazards and data on vulnerability for policy decisions. In particular this is shown for the resulted most impacting weather condition: the drought, measured through the SPEI index, affecting all the country. There are also other hazards frequent and quite impacting, first of all heavy rain. Further improvements of the analysis are programmed in terms of spatial scale, time scale (seasonal approach) and in terms of correlation hazard-vulnerability.

Keywords. Agrometeorology, climate indices, decision support systems, ETCCDI, climate-related risks.

INTRODUCTION

The Common Agricultural Policy (CAP) was launched in 1962 as a strategy to provide affordable food for European citizens and a fair standard of living for farmers[1]. During the last decades, several reforms have been necessary in order to ensure the general goals of the policy in a changing context, in particular referring to the main issues of the environmental protection, the globalization and the challenges posed by climate change (CC), in general covering almost all the United Nations Sustainable Development Goals (SDGs). Given the importance of these global issues for the future CAP 2021-2027, in the new proposal of regulation, the European Parliament introduced, among other innovations, the realization of strategic national plans that reflect a comprehensive intervention logic, a "policy cycle concept" founded on identified and recognised intervention needs, deriving objectives and indicators (at all levels of evaluation) and consequent selected measures that can effectively contribute to reach the targets (European Parliament, 2018). The strategic plans need to start from a "context analysis", describing through objective studies the current conditions, strengths, weaknesses, opportunities and threats (SWOT analysis) with respect to the objectives of the CAP. The context analysis has a core role for the rural development policy, of the CAP, in which the choice of the measures is linked to specific goals to be pursued (environment, climate change, etc.) and to local conditions.

In Italy, the rural development policy has always been programmed and applied at administrative regional level (21 regional programmes, NUTS2), while the new CAP cycle requires a national programming phase, based on a context analysis at national level. This innovation represents an important step forward to have a more coherent and consistent programming phase compared with the past 21 separate regional programmes, nevertheless it also represents a challenge because of the heterogeneity of environmental and agricultural conditions of the Italian territory. For these reasons, a task force has been established by the Italian Ministry of Agricultural and Forestry Policies (MIPAAF), which involves representatives from the Regions, with the idea of a common work path, identifying the analyses to be carried out at national and regional level. The task is supported by technical analyses performed by research institutions, including the Council of Agricultural Research and Economics (CREA) with its researchers involved in the National Rural Network project[2].

[1] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en.

[2] https://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1.

As a starting point, it was agreed to deal with the proposal of regulation containing context indicators and with the thematic documents produced by the European Commission (EC) on the objectives of the future CAP (policy briefs), which provides guidance on how to set the contents required for the context analysis.

A specific thematic policy brief has been proposed by the EC on the general objective 2 "*to strengthen environmental protection and action for the climate and contributing to the achievement of the Union's environmental and climate objectives*", among whose a specific objective 2.1 is "*contributing to the mitigation of climate change and adaptation to them, as well as to the development of sustainable energy*" (EC, 2019; EEA, 2019). The article describes the specific study carried out to contribute to the Italian policy brief on climate change and to the context analysis for future CAP. The objective of the study is also a first attempt to assess the relationships between the agrometeorological context and the impacts on agricultural productions and practices, considering the scenarios currently taking shape, showing an increase in uncertainty of climate conditions directly influencing the agricultural production. The sector is indeed the most exposed and vulnerable to climate change referring to the higher likelihood of weather events extreme and non-extreme leading to natural disasters (IPCC, 2012). At last, the study intends to contribute in exploring the potentialities in agrometeorological analyses of new data sources offered by the European project Copernicus[3].

MATERIALS AND METHODS

General criteria adopted for the context analysis

Referring to the objectives of the study, the first step has been to analyse the EC requirements regarding the contents needed in the context analysis with reference to the climate and the impact of CC in agriculture. As explained in the introduction, the reference documents are the proposal of regulation and the EC policy brief on climate change.

The policy brief reports what it is expected from the context indicators in terms of information: a) changes in precipitation; b) changes in temperatures; c) frequency and intensity of extreme events; d) other references, such as changes in agricultural yields, the period of flowering and in the agricultural calendar.

Moreover, in the proposal of regulation, an impact indicator is requested in the "climate" section: the indi-

[3] https://www.copernicus.eu/en.

cator c.45 “Direct losses in agriculture attributed to disasters”.

The methods for this study were chosen so as to reflect both the EC expectations for the context analysis of the National strategic plan, and the need to ensure a good agrometeorological analysis at national and subnational level, with a specific and new focus on extreme events connected to climate-related disasters risks in agriculture.

The main choice criteria were the following:

- availability of data for the calculations;
- descriptive capacity of the relations between agriculture and weather-climate conditions;
- possibility of representing the indicators with respect to the climate (“changes” of temperature and precipitation);
- preference for statistical distributions at a local scale (percentiles) and not for fixed value thresholds for the estimation of extreme events. This choice is linked to the climatic and agricultural heterogeneity of Italy, which makes the fixed thresholds unsuitable to adequately describe the different conditions.

In addition to the EC approach to the context analysis, the main references for the study are the works of the Intergovernmental Panel on Climate Change (IPCC) and of the Expert Team on Climate Change Detection and Indices (ETCCDI)[4]. Following the IPCC approach, the indicators are divided into: context indicators, corresponding to the indicators of “hazard” and “exposure”; impact indicators, representing the “vulnerability” (IPCC, 2007 and 2012). The context and hazard indicators chosen for the information on “extreme events” derive from the work of ETCCDI, that proposed a set of 27 main indices, based on daily temperature (maximum and minimum) and precipitation values.

Moreover, two specific indices have been added to improve the context description, in relation to the drought conditions and the changes of the phenological calendar, respectively.

As above explained, in relation to the objectives of the analysis, it has been proposed to enrich the analysis of hazards and climatic conditions with an impact indicator, a “vulnerability” indicator in the IPCC approach, defined as “Direct losses in agriculture attributed to disasters” in the proposal of regulation. In fact, the concept of “climate extremes” discussed within the IPCC works is particularly important in agriculture, because the increase of climate extremes likely will lead to more “disasters” defined as “*severe alterations in the normal functioning due to hazardous physical events interacting with vulnerable conditions, that require immediate emergency response*” (IPCC, 2012). In the context of climate change, the disaster risk is influenced not only by hazard, but also by exposure and vulnerability, where the exposure refers to the presence of productive systems where hazard may occur, while the vulnerability is the predisposition to be adversely affected (economic damages due to lack of resilience and low capacities to cope with/adapt to). In the IPCC approach, the climate-related risks should be faced through the improvement of two components of risk management: measures of risk reduction (more stringent where the vulnerability is high) and disaster management (more stringent where the hazard is high). For these reasons, it is important to start changing the approach in policy decisions, integrating the weather and climatic analyses with a vulnerability component (IPCC, 2012; UNISDR, 2015; EEA, 2017). This study is also a first attempt to introduce these integrated concepts in the policy analyses in the agricultural sector.

The indicators have been calculated at sub-national scale, using the classification of territorial units for statistics (NUTS), a geocode standard for referencing the administrative divisions of countries for statistics, developed by the European Union[5]. The first-level NUTS regions (hereinafter also called “areas”), based on major socio-economic areas, has been adopted, precisely for Italy: North-West (Aosta Valley, Liguria, Lombardy, Piedmont); North-East (Emilia-Romagna, Friuli Venezia Giulia, Trentino-Alto Adige/Südtirol and Veneto); Centre (Lazio, Marche, Tuscany and Umbria); South (Abruzzo, Apulia, Basilicata, Calabria, Campania and Molise); Islands (Sardinia and Sicily). Although aware that the agrometeorological analyses poorly adapt to areas on administrative basis, this choice seemed the most suitable compromise to be used in this kind of analysis with institutional purposes at national scale.

The climate reference period (hereinafter referred to as “climate period”) is 1981-2010, according to the World Meteorological Organization (WMO) that defines the “normal standard climates” as the averages of climatic variables calculated for a uniform period of 3 consecutive decades. In 2017, the WMO established that, in addition to the 1961-1990 period, which remains the standard reference period for long-term assessments of climate change, it is possible and recommended to use the new “climatological standard normal” 1981-2010, able to describe more coherently the current climate (WMO, 2017). The need to provide a description as representative as possible of the current climate variability led to choose 1981-2010 as the climate reference period.

[4] http://etccdi.pacificclimate.org/list_27_indices.shtml.

[5] https://ec.europa.eu/eurostat/web/nuts/nuts-maps-.pdf-.

The period chosen for the analysis is 2003-2018, covering enough time (16 years) to describe the current context of the application of a mid-term policy like CAP (7 years cycles).

Data

All the elaborations and analyses of data here presented are original and are based on data from three main sources: a climate reanalysis dataset, for meteorological data, a phenological observation dataset, a database on damages on agriculture due to adverse events derived from the Italian ministerial decrees on damages.

The data source chosen for the meteorological analysis, is ERA5, the hourly climate reanalysis data, available on a regular grid at a resolution of 0.25°. ERA5 is the latest climate reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty (C3S - Copernicus Climate Change Service, 2017).

The choice of the ERA5 dataset is due to several reasons:

- climate reanalysis combines past observations with weather models to generate gridded datasets of consistent and complete time series of multiple climate variables at sub-daily intervals, which are currently the most used datasets in the climate extreme studies (Donat et al., 2014);
- the data are public, produced by a European institutional project (Copernicus);
- the available dataset starts from 1979, covering a good time period for climatic analysis;
- the dataset will maintain continuity over time, allowing analyses able to be updated (this is important also for supporting the policies evaluation through indicators); moreover, data are released every two days, overcoming problems of availability of other datasets;
- further improvements and enrichment of the variables provided in the Copernicus project are planned.

The variables selected in ERA5 (atmosphere) are described in table 1.

The phenological database of the IPHEN network[6] has been used to extract weekly observational data of the grapevine phenological phases on 33 sites, distributed all over the country, for the period 2006-2018.

The data used for the impact indicator derive from damages declarations recognized by the State as due to natural disasters, as assigned by the National solidarity fund for disasters in agriculture of MIPAAF (legislative decree 102/2004). Information from Italian ministerial decrees of damages due to "adverse events" is collected in a database now managed by CREA, reporting data from the 1980s on the date and the kind of event, the location (at level of municipalities) and the declared economic damages on production (at least 30% of losses), farm structures (such as irrigation systems, animal shelters, greenhouses, etc.) or infrastructures connected to agricultural activities (mostly collective drainage and irrigation channels, rural roads, etc.). For the present study, only the weather adverse events have been considered (for instance, earthquakes and volcanic eruptions have been not included). The definition of "adverse event" in the Italian law is an adverse weather such as frosts, storms and hail, ice, heavy rains or severe droughts that destroy more than 30 percent of the average annual production calculated on the basis of the previous three years or a three-year average based on the previous five years, excluding the lowest value e the highest one (legislative decree n. 102/2004). The general criteria used by the Ministry to declare a disaster due to adverse events are the aforementioned threshold of damages and the statistical exceptionality of the event (not the same in the previous 5 years in the same territory), but each case can be differently evaluated. The declara-

Tab. 1. Variables selected in ERA5 for the context analysis.

Name of variable in ERA5	Abbreviation	Measure unit	Transformation of derived variables
2m temperature	2T	K	°C
2m dewpoint temperature	2D	K	Relative umidity min and max (%)
10m u-component of wind	10U	m s-1	Wind speed (m s-1)
10m v-component of wind	10V	m s-1	
Surface solar radiation downwards	SSRD	J m-2	MJ m-2
Total Precipitation	TP	m	mm
Orography	OROG	m2 s-1	Altitudine (m s.l.m.)

[6] https://www.reterurale.it/fenologia.

tion assigns also an economic damage associated to the event in order to compensate farmers.

Moreover, the ISTAT data of the "Surveys on the structure and production of agricultural holdings (SPA)" have been used for the UAA data available for the analysis period[7].

Methods

With reference to the context analysis, among the ETCCDI core indices, four "extreme events" indicators have been selected (warm and cold spell duration indices, a modified version of frost days and very wet day fraction). Moreover, the standardized precipitation evapotranspiration index - SPEI has been calculated because of the importance of monitoring drought events in agriculture. This indicator covers also the issue "changes in precipitation and in temperatures" proposed by the EC policy brief, being the two variables strictly linked in its definition and calculation. An increasingly widespread use of these indicators and indices can be found in the scientific literature, also referred to risk assessment and adaptation policies support (EEA, 2017; Klein Tank et al., 2009; Donat et al., 2013a, b; Russo et al., 2014; Zhang et al., 2011; Zolina et al., 2009). Less references can be found in the agricultural sector, most of them referring to drought indices, although a general increase of the studies in this field has been observed in the last decade (EEA, 2019; Cogato et al. 2019; Blauhut et al. 2015).

A further context indicator is the First flowering date, very important for agricultural productions and practices. Basing on the data availability, the chosen indicator has been calculated for the Grapevine Chardonnay variety.

Finally, an original impact-vulnerability indicator has been defined, mainly based on the economic value of damages affecting production, farm structures and infrastructures.

All the indicators have been aggregated at the NUTS1 region level using the official administrative boundaries from the Italian National Institute of Statistics (ISTAT), updated to the 1st of January 2019[8] and transformed from the projected EPSG: 32632 to the geographical EPSG: 4326 reference system[9], the same adopted by the data distributed through Copernicus climate data store. Data have been spatially aggregated, using the median value of the cells intercepted by the administrative boundaries, unless for the SPEI index, for which the 10th percentile has been adopted (Bachmair et al., 2015), with the aim to investigate the link with the impact-vulnerability indicator values.

Data processing has been performed through specific libraries of the R software ("climdex.pcic" and "SPEI"). R is an open source statistical software released under the GNU general public license (GPL)[10].

Warm spell duration index - WSDI

The warm spell duration index is the yearly number of days belonging to warm spells, defined as at least 6 consecutive days with maximum temperature higher than the 90th percentile of the distribution of maximum daily temperatures in the same period of the year over the 30 years of climate. Recently, the negative correlation between wine quality and the incidence of heat waves has been investigated by Blanco-Ward et al., 2017.

Cold spell duration index - CSDI

The cold spell duration index is the yearly number of days belonging to cold spells, defined as at least 6 consecutive days with minimum temperature less than the 10th percentile of the distribution of minimum daily temperatures in the same period of the year over the 30 years of climate. This index is generally calculated within a set of indices (see references above), in some cases strictly associated to WSDI (Song et al., 2018).

Late frost days - LFD

Starting from the original indicator FD of ECCTDI, this indicator is based on the count of the frost days limited to the period March -April, when most of crops are in the phenological phase most sensitive to frost (flowering), with reference to the area study and as reported by Gobin (2018), who analysed the spring frost days during the sensitive crop stages. The indicator is expressed as the yearly deviation from the climate values [LFD_{year} - $LFD_{Climate}$], which correspond to the median of the distribution of the annual values during the climate period.

As frost days are considered all the days with a minimum temperature equal to or less than 0 °C. This generic threshold of 0 °C is due to the purpose of the analysis, that doesn't consider local conditions and specific crops. Furthermore, to detect the wheat's frost-susceptibility, this threshold has also been adopted by Zheng et al. (2015).

[7] http://dati.istat.it/.
[8] https://www.istat.it/it/archivio/222527.
[9] https://www.epsg-registry.org/.
[10] https://cran.r-project.org.

Very wet day fraction - R95pTOT

This indicator represents the yearly amount (in millimetres) of the daily precipitation above the 95th percentile of the distribution of daily rainfall of the wet days (greater precipitation than 1 mm) in the climate period. The values are also expressed as percentage contribution of R95pTOT to annual total precipitation. This index has been already used to investigate the impacts of heavy rains on wheat (Li et al., 2016) and rice (Subash et al., 2011).

For this indicator, an additional analysis has been carried out to compare the mean value resulted in the analysis period to the mean value calculated for the previous not-overlapping period 1981-2002.

Standardized precipitation evapotranspiration index at time scale of 6 months – 6-month SPEI

SPEI represents a simple climatic water balance (CWB), also known as "effective precipitation", calculated as difference between total precipitation and potential evapotranspiration (PET), here estimated through the Penman-Montheit equation (Allen et al., 1998).

The indicator has two important peculiarities. The first is that it can be computed at different time scales, incorporating the influence of the past values (Vicente - Serrano S.M. et al., 2010). Thus, the value calculated for each month considers the values of the previous months, with a different time scale (from 1 to 48 months) which depends on the aims of the analysis (assessment of meteorological, agricultural or hydrological drought). In the study, the time scale chosen is 6-month, considered more suitable to describe water stresses during the agricultural season. The second peculiarity is that the SPEI calculation is based on the comparison between the CWB recorded in an interval of *t* months (where *t* = 1, 2, ..., 48 months) with the distribution of the CWB in the climate period for the same interval. For each cell, the time series of cumulative effective precipitation is interpolated by means of a log-Logistic theoretical probability distribution with the unbiased fitting method probability weighted moments (Vicente - Serrano S.M. et al., 2010), assuming a rectangular kernel that assigns the same weight to all months of the interval of 6 months. The tail values of SPEI <-2.5 and SPEI$> +2.5$ have been cut according to what suggested in literature, mainly when short time series are considered (Vicente-Serrano S. M. et al., 2016).

The SPEI drought index is classified by the scientific community in different classes of intensity[11] (WMO and GWP, 2016) (Tab. 2).

[11] https://spei.csic.es/home.html.

Tab. 2. Classes of values of SPEI.

Classes of intensity	SPEI values
EW - Extreme wet	≥ 2.00
SW - Severe humidity	1.50 ÷ 1.99
MW - Moderate humidity	1.00 ÷ 1.49
N - Near normal	-0.99 ÷ 0.99
MD - Moderate drought	-1.00 ÷ (-1.49)
SD - Severe drought	-1.50 ÷ (-1.99)
ED - Extreme drought	≤ (-2.00)

The elaborations are here reported with the values of March as representative of the recharge seasons (October-March) and with the single values from April to September, useful to monitor the drought during the growing seasons.

Grapevine first flowering date -FFD (cv. Chardonnay)

The indicator is expressed as yearly deviation from the climate values [FFD_{year} - $FFD_{Climate}$], which corresponds to the median of the first flowering dates during the climate period. The first flowering corresponds to the 61 value of the BBCH scale (Meier, 2001). The FFD indicator is calculated using the IPHEN phenological model for the estimation of grapevine flowering dates for each year both of the analysis and climate periods. The model, adopted by CREA for producing a weekly phenological bulletin at a national scale[12], has been developed within the IPHEN project (Mariani et al., 2013; Cola *et al.,* 2012). It is based on the calculation of normal heat hours (NHH) (Wang and Engel, 1998; Weikai and Hunt, 1999). The accumulation of NHH is converted to phenological phases, according to the BBCH scale, through empirical equations obtained by regression on both historical NHH and phenological data detected in the field.

To check the IPHEN model performance in simulating flowering dates, the mean absolute error-MAE between the flowering dates simulated and those observed in the field has been calculated.

Considering that the altitudes of ERA5 cells and phenological observation sites may be dissimilar, the

[12] https://www.reterurale.it/bollettinofeno.

link between the differences of elevation and those of flowering date (MAE errors) has been investigated, by a linear regression, with the aim of verifying whether this uncertainty source can affect the model performance.

Damages attributed to natural disasters

Referring to the impact-vulnerability indicator, the chosen indicator "Economic damages attributed to disasters on utilized agricultural area" (euro/hectare of UAA) is based on the above-mentioned database on data of damages recognized by the State as due to natural disasters, as assigned by the National solidarity fund for disasters in agriculture of MIPAAF.

The calculation of the economic value of impacts on production is based on the UAA involved and the official prices at the time of the event of the affected crops, while for structures and infrastructures is based on the physical damages and the prices of rebuilding/repairing. These data produced with the same criteria are an important point of reference to assess the impacts in different periods and areas. Nevertheless, it is important to specify that they are slightly underestimated in terms of absolute values because of the exclusion of insured crops (foreseen by the law, but less than 18% of national production in 2015) (Pontrandolfi et al., 2016).

The UAA data from ISTAT have been used for creating a complete series from 2003 to 2018. As original data cover only the years 2003, 2005, 2007, 2010, 2013, 2016[13], missing annual data have been covered by the nearest previously available value: e.g. 2003 data applied also to 2004 and so on.

The geographical reference units for the elaborations are the NUTS1regions and the indicator has been calculated as yearly values of total damages per hectare of UAA.

Further elaborations are presented referring to the kind of damages (on production, farm structures or infrastructures) and to the kind of events producing damages.

RESULTS

The SPEI data in figure 1 show two cases of widespread severe and extreme drought phenomena: 2003 and 2017, with extreme drought in 2003 in Centre and North and in 2017 in Centre, South and Islands. Another similar phenomenon, although of lower intensity, is noticeable for 2007 and 2012; it involved almost all NUTS1 regions, unless the Islands. This latter region was instead affected by a moderate/severe drought during 2016. In some cases, drought conditions, at least moderate, affected the recharge periods (March) almost all over the country, mainly in 2007, 2012 and 2017. A prolonged drought condition interested the Northern regions from 2003 to 2007 and 2011-2012 in northern and central Italy but with less intensity. As regards wetness events during the observed period, only few cases are remarkable: South in 2009, Centre in 2010, Centre and North-East in 2013, Centre in 2018 show wetness conditions from moderate to severe. These phenomena resulted to affect mainly Centre.

The results of warm and cold spell indices are reported in the figure 2. Referring to the warm spells, the most critical years result to be 2011 and 2003, followed by 2007 and 2015. In details, in 2011 the maximum values were reached in the northern and central regions, with a peak of 45 in North-East. In 2003, warm spells were widespread all over the country, with WSDI values of at least 30 in 4 of the 5 NUTS1 regions. On the contrary, the years less interested by warm spells were 2004, 2005, 2008 and 2010. In general, the second half of the analysis period results to be more continuously affected by these phenomena.

The cold spells are in general less widespread all over the country and the values result to be lower than warm spells in terms of days. Few years show the occurrence of these phenomena: the most relevant in the North-West, with peaks of 15 days in 2012 and 10 in 2005; single events of cold spells occurred in northern regions (2003), South (2006, 2009 and 2017), Islands (2005 and 2009). It is noticeable that almost all events are concentrated in the first 10 years of analysis.

The results on late frost days are shown in the figure 3. The data show positive anomalies in 2005 in all the regions and in 2010 in the North. The number of late frosts is below average in 2007-2009 and after 2013 there is a clear tendency to reduction of late frosts (each year below the average), most accentuated in the north-eastern and central areas. A different behaviour is present in the Islands, where the late frost days are near normal, except a weak positive anomaly in 2005.

In figure 4, the indicator R95pTOT (very wet days) is represented in millimeters and as the percentage fraction of the total annual precipitation, in order to allow a better comparison among the different cases. The distribution of these phenomena shows that, even though different rainfall regimes are present within the country, a heavy rain fraction is always represented among the years and the areas, with an average of 20% and a range between 10 and 31%. In general, the percentage

[13] http://dati.istat.it/.

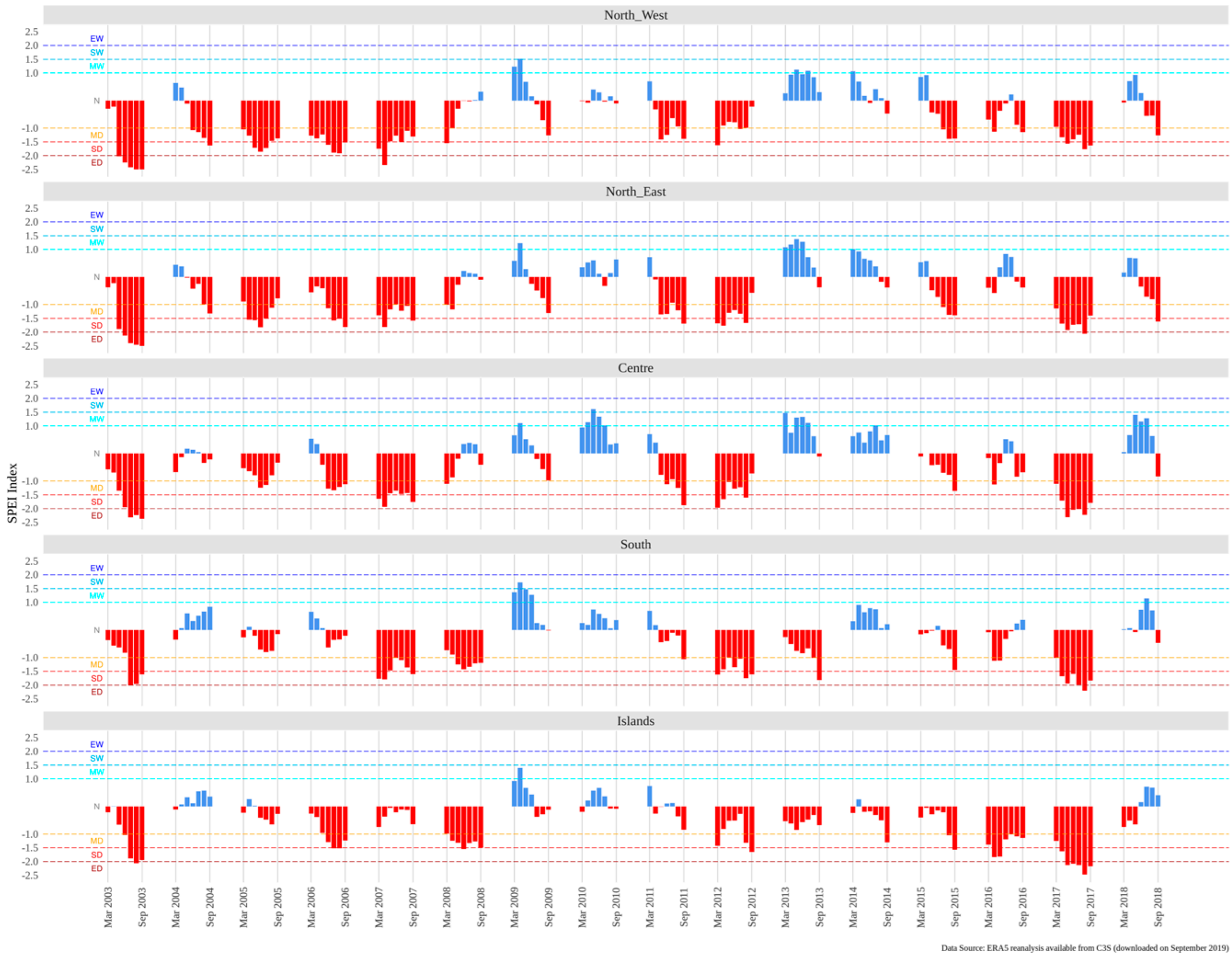

Fig. 1. Standardized precipitation evapotranspiration index – 6-month SPEI, monthly values in the period 2003-2018 (class description in Tab. 2).

values vary among regions, but they all show high values, from 24% in the Centre to 30% in North-West and Islands, in the year 2010 (the second rainiest year in the period). Another important indication is that in the 16 years period the heavy rain amounts have been most relevant in South and Islands, with a mean value significantly higher than in the previous period 1981-2002: the increase is equal to 42.4% (*p.value* 0.0006) and 44.7%, (*p.value* 0.003) in South and Islands respectively.

At last, the indicator of first flowering date shows between-year variability in terms of deviation from average (Fig. 5). Anomalies can be observed in 2004 with generalized late flowering around 7–12 days and in 2007 with generalized early flowering around 10-16 days. From 2012, Centre, South and Islands present a widespread advanced flowering until 16 days. In 2013 and 2016 a significant latitudinal gradient of temperatures divided Italy in two parts, with the northern regions presenting a late flowering while the central, southern and island regions an advanced one. The median MAE value has resulted to be equal to 5 days at a national scale and significantly affected by the differences in elevation between gridded and site dataset. In fact, the relationship between MAE and differences in elevation has showed that the 65% of FFD variability can be explained by these differences (adjusted r-squared= 0.65, *p.value* $<2.2e^{-16}$).

Referring to the indicator of impacts, the results show significant damages due to natural disasters meteorological-related all over the country in 2003 and 2017, corresponding to the most severe droughts, followed by 2012 (Fig. 6). In these years, the highest values range from 300 to 600 euro of damages per hectare of UAA. The most affected region is North-East, with highest damages per hectare in 2003 and 2012 and the second highest in 2017, after Centre (with 614 €/ha). The persistent conditions of drought in the period 2004-2007 in the North of the country (Fig. 1) don't correspond to the damages, less pronounced. On the contrary, in 2003-2007, South and Islands show relevant damages although with no or moderate and less persistent drought than in North.

In total, it has been calculated a damage of 27.837 billion euros declared in the 16 years, 76% of which are damages on productions, 18% on farm structures and 8% on infrastructures connected to the agricultural activities (Tab. 3). The highest absolute values of damages affected the Islands and the South, followed by the North-East. The Islands also suffered the major damages on productions and on farm structures and the South on infrastructures. These data, comparing to the intensity of the events, in terms of hazard showed before, seem define the Islands and the South of Italy more vulnerable to damages than exposed to the hazards.

The kind of event affects differently areas and type of damages (Fig. 7). The number of events declared as natural disaster classified per type of damage show that the episodes of heavy and/or prolonged rain are frequent and affect all three productions, structures and infrastructures (these ones almost exclusively hit by heavy rain), while several strong winds and tornados mainly hit the farm structures. The damages on productions are due to several kind of events, mainly drought, hail and heavy rain.

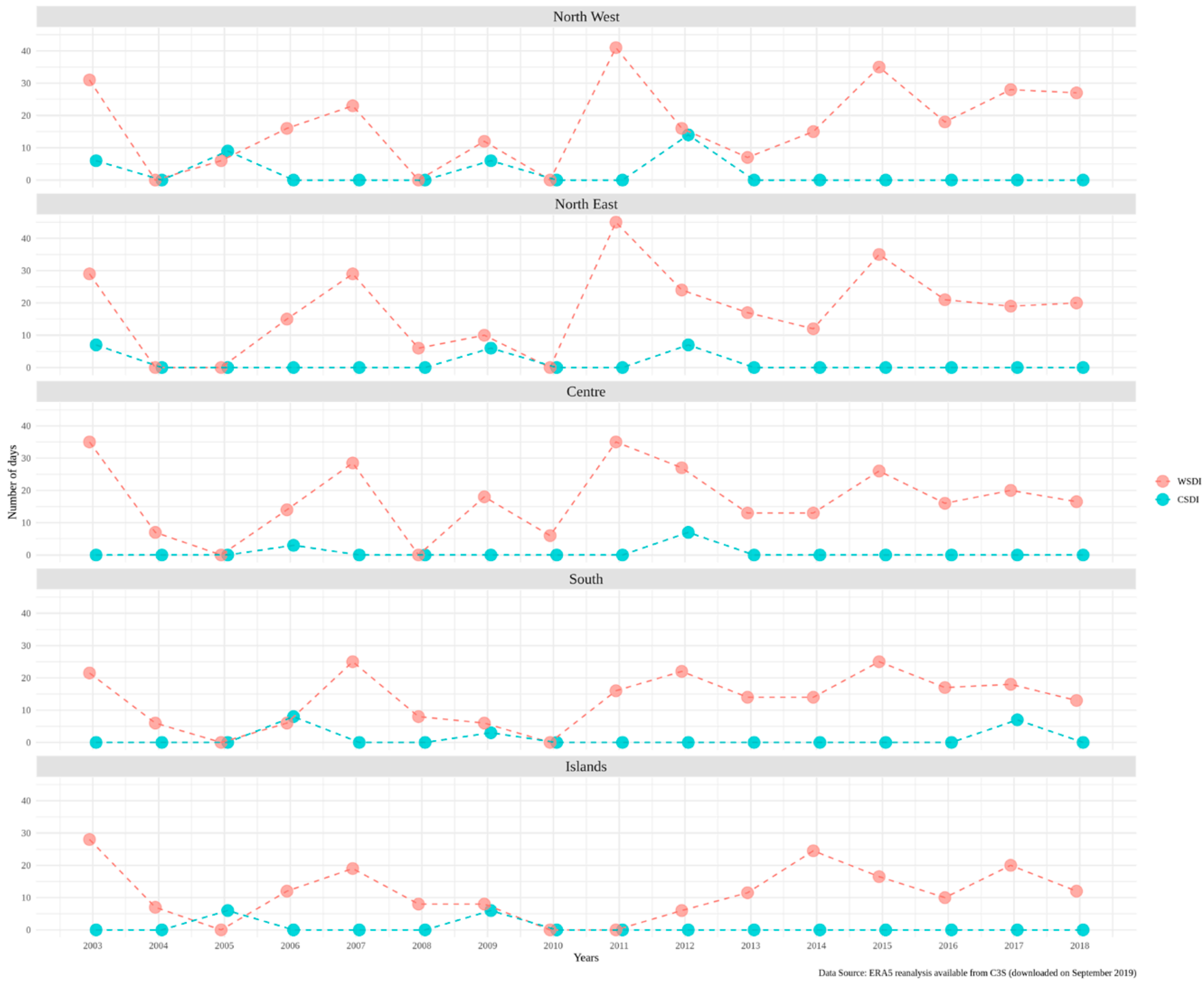

Fig. 2. Warm spells and cold spells, number of days per year in the period 2003-2018.

Fig. 3. Late frosts days, deviation from the climate per year in the period 2003-2018.

DISCUSSION

The context analysis here presented provides a first description of the relationships between damages on agriculture and weather-climate conditions, despite the small scale necessary for the National Strategic Plan.

In particular, the results show that drought has been the most impacting hazard and a frequent condition affecting all the country around every 4-5 years, with extreme peaks in 2003 and 2017. Moreover, considering the climatic characteristics of the different areas of the country, in South and Islands the drought events are less extreme than in North, in terms both of hazard and impacts (see Figg. 1 and 7). The positive relationship between drought and damages did not occur everywhere: for example, lower damages have been recorded for the persistent drought occurred in the northern areas in the period 2004-2007 (Fig. 1), while relevant damages occurred in South and Islands in 2003-2007, although these areas showed no or moderate and less persistent drought in relation to North. These results confirm that the link between drought and impacts is time variant and region specific (as already noticed by EEA, 2017; Bachmair et al., 2015 and Blauhut et al., 2015). In the investigation of this link, it would be also important to consider other factors such as the level of spatial aggregation (i.e. NUTS1), mainly in climatically heterogeneous areas, and the type of agricultural production (Parsons et al., 2019; Gobin, 2018).

The second most important event is heavy rain: the results show that the country has a general intense and concentrated precipitation hazard. The concentrated precipitation in average is equal to 20% of annual total precipitation. Overall, there is a variability of this phenomenon during the analysis period and among the different NUTS1 regions. In particular, the heavy rain amounts have been most relevant in South and Islands, with a mean value for the analysis period significantly higher than in the previous period 1981-2002, meaning a change of pattern in precipitation distribution in time.

Heavy rain is the hazard that affects at the same time productions, farm structures and infrastructures and in some cases, as in Islands for 2012 and 2015, these phenomena during the year are associated to drought events, with potential huge impacts on entire agricultural seasons.

Another significant indication comes from the warm spells, which affected the whole period, with a major frequency in its second half, while the cold spells are rarer, with few events concentrated in the first 10 years of analysis, even though the general threshold adopted for this index (0 °C) is not suitable to investigate the different hazards due to late frosts, which vary with the site, the season and the crops.

The late frost days after 2013 show a clear tendency to reduction (all the years below the average), most accentuated in the north-eastern and central areas.

The results on the indicator of first flowering show a generalized early flowering from 2012 in the Centre, South and Islands.

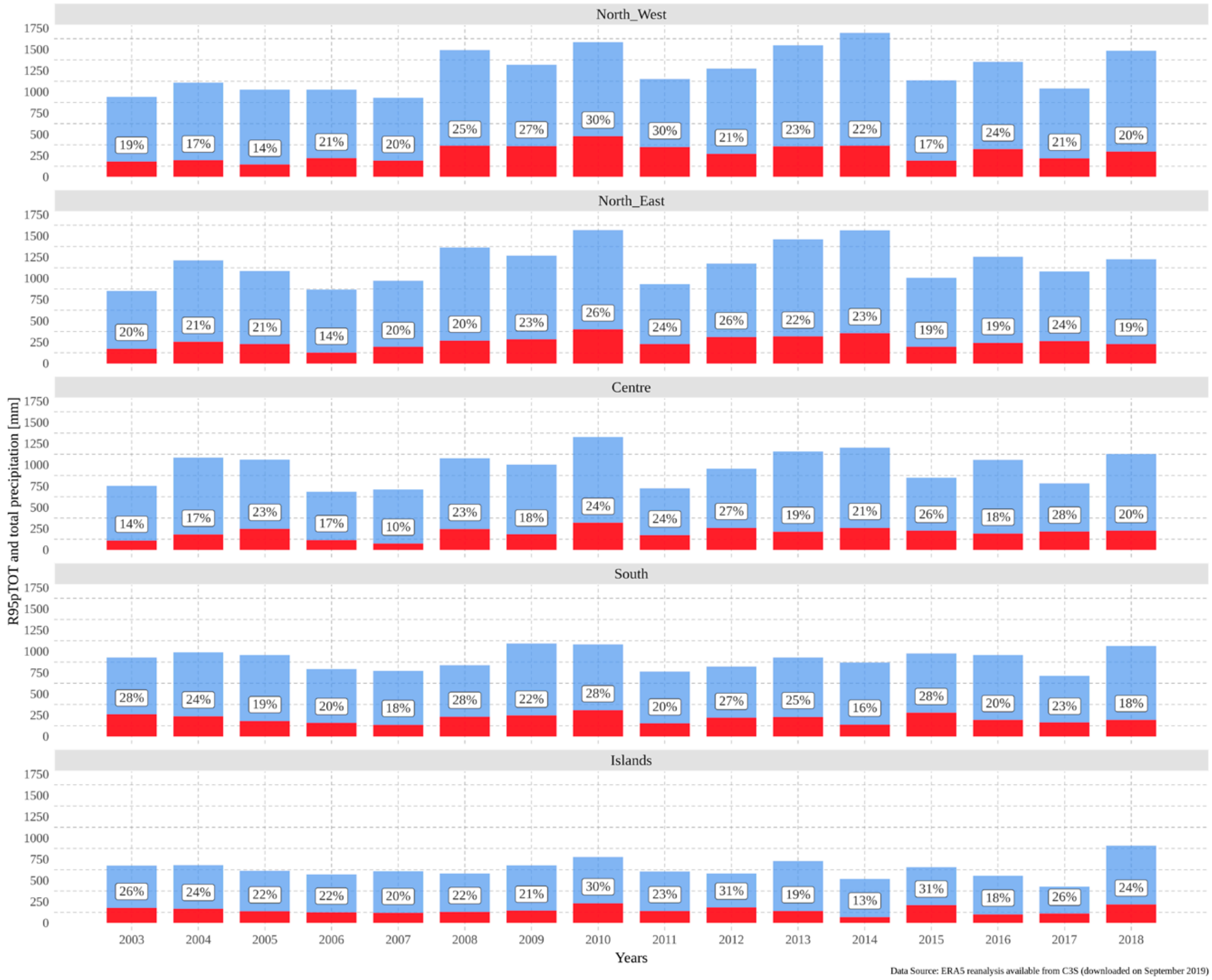

Fig. 4. Annual total precipitation (blue bar) and precipitation fraction due to very wet days (red bar and %) per year in the period 2003-2018.

The joint analysis of some hazard indicators highlights some consistent signals in relation to particular years or sub-periods. In 2004, the relevant delay of first flowering is consistent with the almost absence of warm spells, on the contrary, a negative link between flowering and warm spells is evident, all over the country in 2007 and mainly for northern regions in 2011. In addition, a persistent advanced flowering in the second part of the analysis period is consistent with a general increase of warm spells, especially in South and Islands.

As regards the choice of indicators, some of them need to be assessed at a more detailed spatial scale and to be focused on the specific requirements of the different crops. In addition, local specific thresholds could improve the analyses.

The results of SPEI, late frost days, first flowering date and warm spells seem strictly linked to the undisputed increase of average temperatures in the last years also in Italy (ISPRA, 2019).

In general, the country shows a high vulnerability to weather events leading to disasters, with a huge amount of damages declared (almost 30 billion euros) in these 16 years and frequent high values, normalized to the hectares of UAA, which are greater than about 300 up to 600 euros. The highest absolute values of damages affected the Islands and the South, followed by the North-East and these data, cross-read with the intensity of the events, seem define the Islands and the South of Italy more vulnerable to damages than exposed to the hazards. For instance, in terms of kind of event, the highest damages are due to drought events, while the most frequent events are others, such as hail and heavy rain (both frequent and damaging), while other events are more frequent and less damaging (strong wind).

A crucial point in this analysis is the choice of metrics (i.e. median or 10th percentile) for spatial aggregation: in fact, it is important to choose the most effective metric to highlights the phenomena, particularly in a very orographically complex area like Italy. Some uncertainties are due to the resolution of input data, as in the case of first flowering: the correlation of phenological model errors (MAE) with differences in elevation between the ERA5 cells and observation sites confirms such uncertainty, as suggested by Fehlmann et al. (2019).

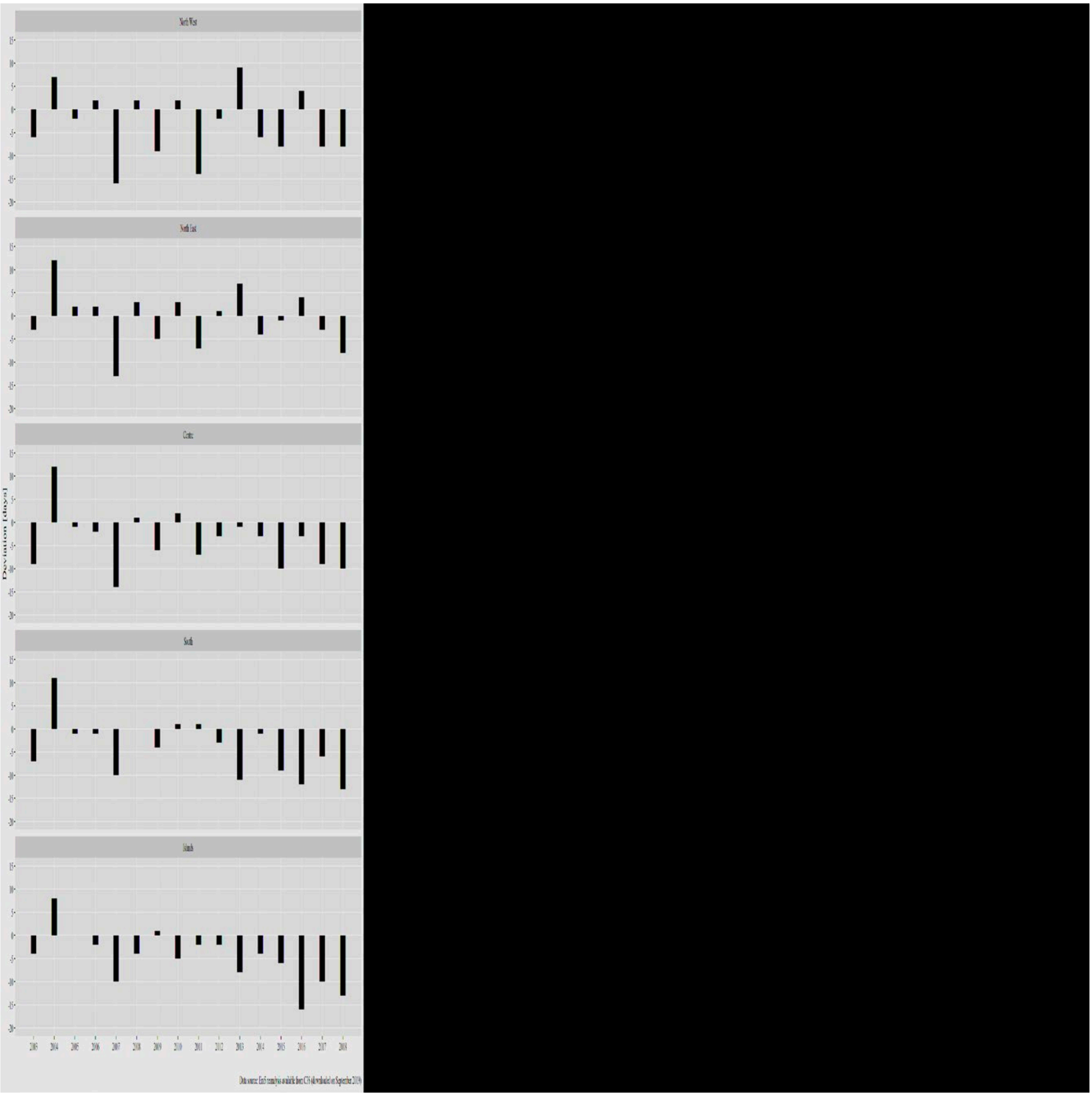

Fig. 5. Annual deviation of first flowering dates from the median (corresponding to 0 value on the y axis) of the climate period. The median dates correspond to 3 of June (DOY, day of the year = 154) for the North West, 27 of May (DOY=147) for the North-East, 28 of May (DOY=148) for Centre, 25 of May (DOY=145) for the South and 16 of May (DOY=136) for the Islands.

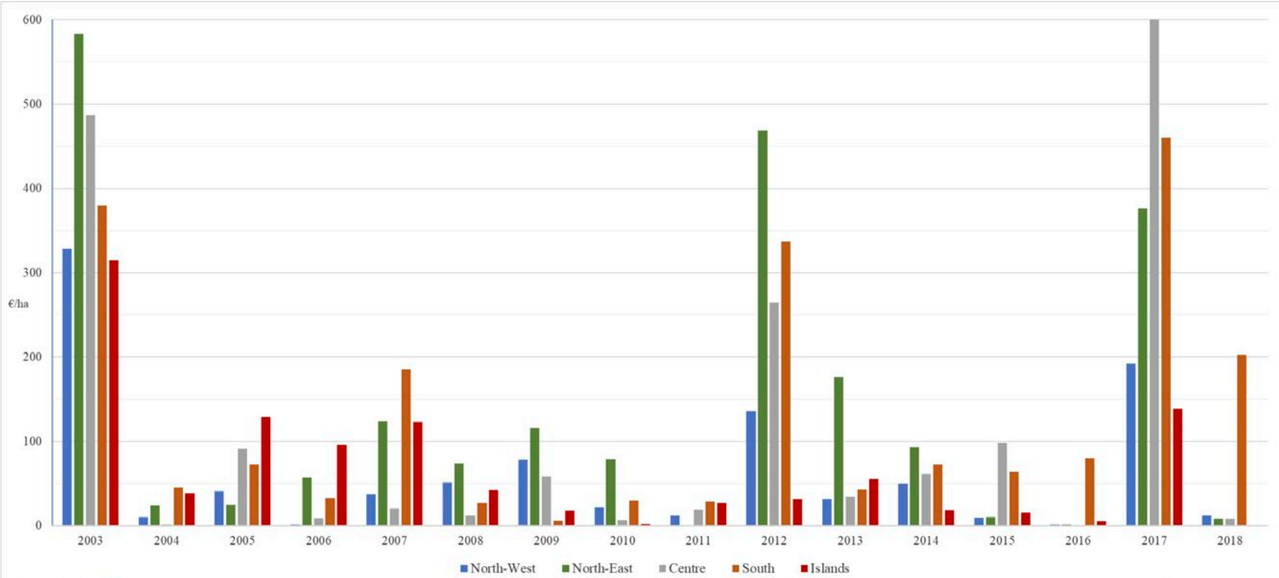

Fig. 6. Damages attributed to natural disasters per NUTS 1 region per year in the period 2003-2018 (values in €/ha UAA).

CONCLUSIONS

Referring to the aims and the context of the study, the results suggest the adoption of policy measures designed through objective analyses instead of simple "perception" of hazard and risks. This aspect has emerged by cross-reading the results of the hazard indicators in terms of intensity and occurrence in time and space and those of the impact indicator (damages due to natural disasters), that in some cases confirm, but not in others, the relationship between hazard and impacts. Moreover, the policy measures need to be enhanced at local level in terms of risk reduction where the agricultural systems are highly vulnerable (the hazard and the impacts are not aligned) and in terms of adaptation to CC and disaster management where the impacts are linked to objective high hazards. For future studies it will be important also to consider indicators for events such as hail and strong wind and some indicators correlating more directly the hazards and the vulnerabilities at territorial level for each kind of adverse event.

Tab. 3. Damages attributed to natural disasters in the period 2003-2018 per NUTS 1 region (values in billion euros).

NUTS 1 Region	Damages on productions	Damages on farms structures	Damages on infrastructures for agriculture	Total
North-West	1,542	0.298	0.290	2,131
North-East	4,716	0.433	0.350	5,499
Centre	3,088	0.629	0.232	3,950
South	5,566	1,201	0.447	7,214
Islands	6,369	2,350	0.323	9,043
Italy	21,283	4,912	1,642	27,837

A possible weakness of the study is the spatial resolution of the input meteorological data, that could be not completely suitable for agrometeorological analyses. In addition, the NUTS1 spatial aggregation chosen due to the needed synthesis for the national context could flatten the phenomena too much; better indications for policy choices could derive from a regional/sub-regional aggregation (NUTS2/NUTS3).

Nevertheless, the study indicates good potentialities of the ERA5 data source for the purpose above explained (Italian national context analysis). In order to give more specific indications for agricultural policy decisions other options will be explored for future studies, such as ERA5-Land which provides higher resolution[14], but shorter time series (from 2001 onwards).

Further improvements are also planned in terms of time scale, for instance using a seasonal approach, important for programming adaptation actions of the agricultural activities.

[14] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview.

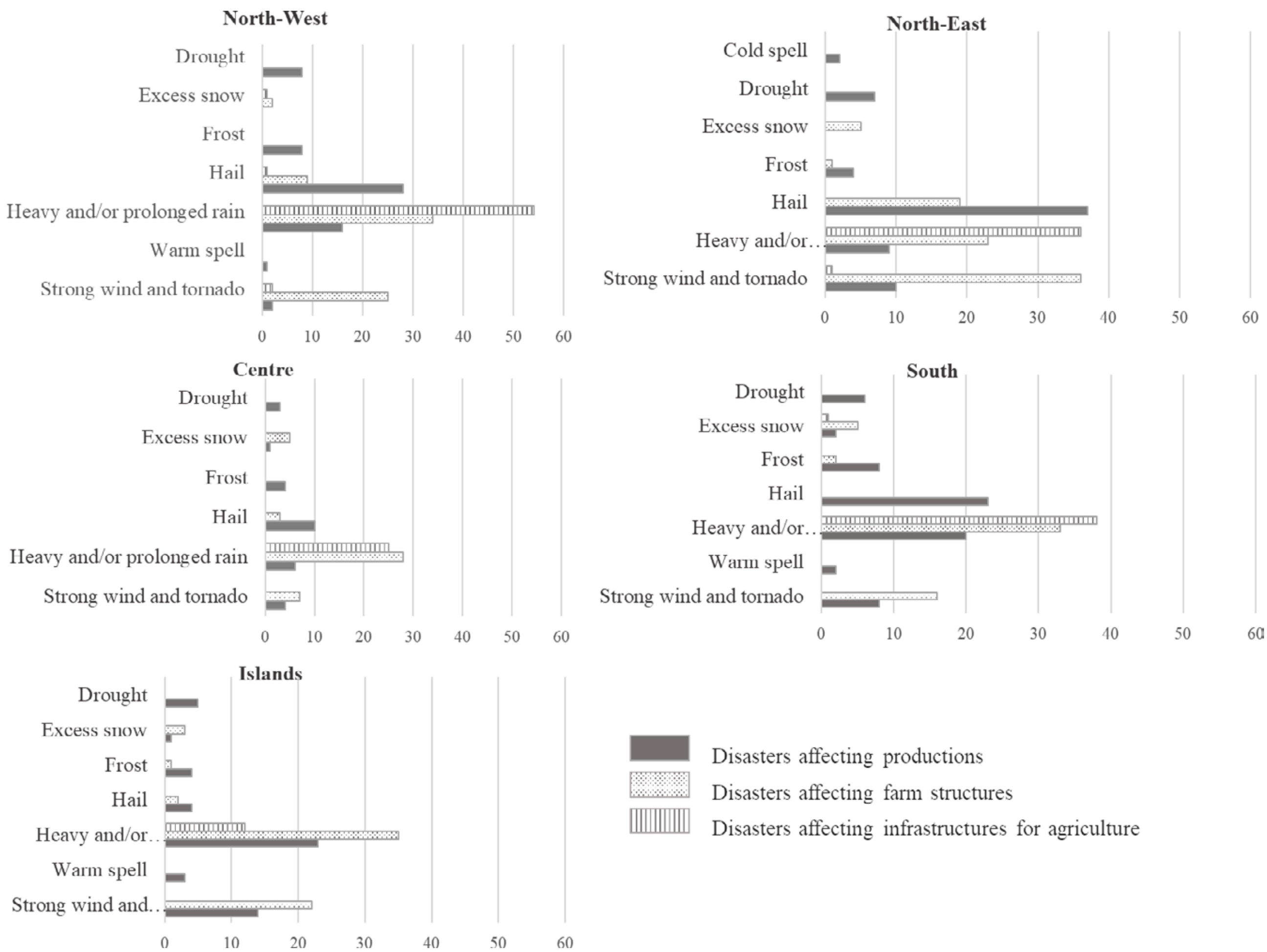

Fig. 7. Number of disasters declared per NUTS 1 region, type of event and type of damages in the period 2003-2018.

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