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A multivariate approach for the study of environmental drivers of wine economic structure

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ABSTRACT

Vitivinicultural “terroir” is a concept referring to an area in which the collective knowledge of the interactions between environment and vitivinicultural practices develops, providing distinctive characteristics to the products. The effect of the environmental components over the terroir wines has been already widely demonstrated, but their possible effect on the overall system of production and organization of the viticultural farms and wine industry, called “wine economic structure” in this study (WES), is still unknown. Thus the research hypothesis of this work was that there are environmental drivers influencing WES.

The investigation was carried out at the national scale, taking Italy as study area, the biggest wine producer of the world. We used viticultural territories singled out at 1:500,000 reference scale, called viticultural Macroareas, which grouped Denomination of Origin areas with respect of geographic proximity, environmental features, viticultural affinity, and wine tradition. The characterization of WES was based on the official data reported in the wine production declarations related to the year 2008. Statistics were taken into account about general quantitative variables of wine farms, presence of associative forms, degree of vertical integration of wineries, quality orientation of wine producers, and acreage of vineyard. Environmental variables related to climate, soil, and vegetation vigour were selected for their direct influence on the vine growing. A second set of variables was chosen to express the effect of land topography on viticultural management. A third one was intended to discover the possible relationships between WESs and land qualities, such as the indexes of sensitivity to desertification, the soil resistance to water erosion, and land vulnerability. A multivariate approach was carried out to elaborate the many studied variables and their interactions. Nonparametric statistics were also used, to overcome the necessity of normal distributions. A PCA was carried out separately for the environmental and economic data, to reduce the dimension of datasets. The new economic and environmental synthetic descriptors were submitted to three multivariate analyses: (i) the correlation between economic and environmental descriptors, through the non-parametric Spearman test; (ii) a cluster analysis to group the Macroareas in few homogeneous WESs; (iii) a discriminant analysis of economic clusters and environmental factors, to highlight the environmental drivers of WESs. The results highlighted that in some Macroareas there is a direct correlation between high quality wine production and presence of low available soil water, due to both soil and climatic limitations. In other Macroareas, the limited quantity and quality of wine yield showed a significant relationship with the presence of rough morphologies and high environmental variability. Similarly, heterogeneous soil and morphological conditions fitted well with both the absence of well-defined economic structures, and a relatively lower quality production. The cluster analysis identified six main WESs for the whole country. Climatic, pedoclimatic, morphological mean conditions and topographic heterogeneity of Macroareas had the most important discriminant power over the clusters. The result of this multivariate analyses proved that the different WESs of a country are significantly influenced by specific landscape characteristics. Therefore, landscape care has a strategic role also on the development of the wine industry.

1. Introduction

Along with the raising economic relevance of food quality over the years, the awareness about the role played by the environ-

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mental traits of land in determining food characteristics has also increased (Vaudour et al., 2015). This awareness has reached a general consensus for wine. The acknowledgment of the influence of land on the style of wine led to the formulation of the *terroir* concept (OIV, 2010). Actually, the studies on terroir have largely demonstrated that quality of grapes is often associated with soil, climate, and other physical land components (Van Leeuwen and Seguin, 2006; Costantini and Bucelli, 2014). In addition, it is known that landscape characteristics of the growing area not only contribute to determine grapevine quality, but also have an effect on the wine quality perception by consumers, as well as on the estimated price of the wine bottle (Tempesta et al., 2010).

In a large wine producing country, there are several systems of production and organization of the viticultural farms and wine industries, called "Wine Economic Structures" in this study (WESs), which are often addressed to different quality targets. Recent studies highlighted that a high wine quality target can be associated with an efficient vertical coordination between the phases of production and processing (Malorgio et al., 2013), or a small size of farms (Fernández-Olmos et al., 2009; Goodhue et al., 2003) and a strong linkage with the territory (Giraud-Héraud et al., 1998). Other studies have demonstrated that wine industries exhibit substantial structural differences across various regions around the world. These structural differences being driven by institutional heterogeneity and contrasting patterns of historical development (Roberto, 2011). However, no quantitative analysis exists about possible linkages between environmental characteristics and WES. One reason is that the relationship between land characteristics and wine quality has been mostly found at the detailed or semi-detailed scales (Vaudour, 2002), while the study of WES is usually carried out at broader scales (Malorgio et al., 2013). Another reason is that relating WES to the environment needs a large wealth of data about land as well as economic variables, for territories as large as regions or nations, which is seldom available.

Studies have already applied multivariate techniques to investigate complex interactions between terroir and wine chemical and sensorial properties (Douglas et al., 2001; Bendell et al., 1999; Martens and Martens, 2000; Naes et al., 2002). Terroir units have been singled out by applying PCA and clustering algorithms on environmental variables (Nuñez et al., 2011; Sotes et al., 1996). Priori et al. (2014) mapped viticultural terroirs at the province scale (1:125,000) with a combined multivariate and geostatistical methodology.

The aim of this work was to answer the following research hypotheses:

i) there are WESs in Italy that can be revealed through a multivariate statistical analysis;
ii) there are environmental drivers of WESs.

The study was carried out at the national scale to have a wide and representative range of vitivinicultural conditions, and using a multivariate statistical approach, to appreciate the many and complex relationships between environmental and economic viticultural variables.

2. Materials and methods

2.1. The study area

The study was conducted in Italy, the world largest wine producing country (48,869 thousands of hectolitres in the year 2015).Territories of sub-regional size that include vineyards protected by a Designation of Origin (DO) were grouped to form "vitivinicultural Macroareas" by Pollini and collaborators (Pollini et al., 2013). Macroareas were lands with same pedological and climatic features, geographical proximity, and similar wine tradition. They showed a high degree of homogeneity at the reference scale of 1:500,000. We selected 32 out of the 92 Macroareas of the "Atlas of the territories of Italian wine" (Pollini et al., 2013), randomly distributed across the country (Fig. 1). The 32 Macroareas resulted well representative of the environmental features of the Italian vineyard.

2.2. Economic data

The study was based on the statistics of the wine production declarations of the year 2008 (AGEA, 2008). The available data, published at the municipality scale, were grouped according to the DO areas. Moreover, the wineries were reclassified on the basis of the "degree of vertical integration" and three classes were distinguished.

1. Integrated farm winery (AGR). It is a vertically integrated type of winery, where both the production of grape and the winemaking take place. An integrated farm winery may transform both own produced and purchased grapes.
2. Industrial winery (IND). This winery processes only grapes purchased on the marker.
3. Wine cooperative (COOP). This winery processes grape produced by members and purchase.

We considered the following quantitative variables:

- General quantitative variables of the wine producers: total number of wine producers (NwF); total vineyard surface (VS) and average surface of the farms (VSm); total grape production (GP), its average value (GPm), and total wine production (WP);
- Presence of independent farms producing wine: proportion of independent farms on the total number of farms (IFn), surface proportion of the independent farms on the total vineyard surface (IFS); mean surface of the independent farms (IFSm);
- Structure of the winery system: number of wineries (NW) and mean capability of the wineries (CWm);
- Degree of vertical integration: production of each winery class on the total wine production (respectively AGR%, IND%, and COOP%);
- Quality orientation of the wine producers: proportion of wine of protected denomination of origin (DOP%), protected geographic indication (IGP%) and table wine (TAB%) on the total wine production;
- Acreage of vineyards: proportion of (i) potential wine growing area (i.e., agricultural area at altitude less than 800 a.s.l.) on total surface (Pv%) and (ii) existing vineyards on "potential wine growing area" (Ev%).

2.3. Environmental data

Among the great wealth of candidate environmental variables that might have been considered to unveil the drivers of WES, we did not consider the characteristics of the infrastructures (e.g., roads and communication facilities), or population (e.g., density, education, richness), but we limited our focus on the main aspects of the biophysical traits of land that are known to interact with grape quantity and quality, as well as with viticultural management and soil conservation (Vaudour, 2002; Costantini and Barbetti, 2008).

2.3.1. Variables affecting vine growing potential: climate and soil

Climate and soil are the main environmental features shaping the terroir effect. Historically, many climate parameters have been used to assess the climate structure of viticultural regions (Winkler et al., 1974; Huglin, 1978; Gladstones, 1992; Fregoni, 1998, 2003;

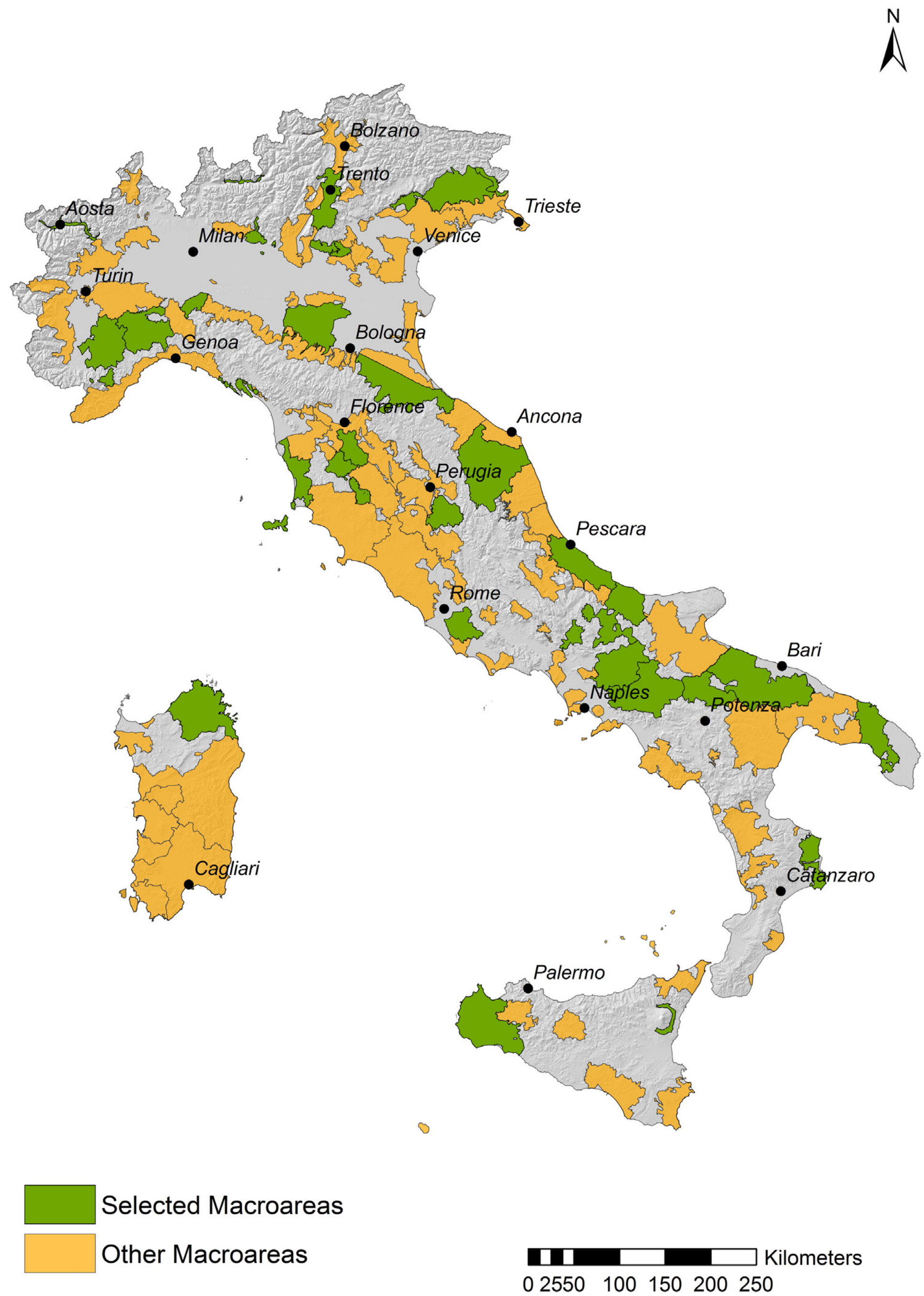

Fig. 1. Selected viticultural Macroareas (A.2, Adriatic coast zone; B.1, Vulture; C.2, Ionian Crotone zone; D.1, Valtellina; D.3, Franciacorta and Brescia hills; D.6, Oltrepò Pavese; E.2, Lambruschi of Emilia lands; E.3, Romagna hills; F.1, Friuli Grave; F.3, Eastern hills of Friuli; G.2, Bari Lands; G.4, Salento area; H.2, Central hills; I.6, Sannio; I.7, Irpinia; L.1, Eastern coast; M.1, Molise; N.1, Gallura; O.2, Bolgheri and Etruschi coast; O.6, Montalcino and Siena lands; O.8, Chianti Classico; P.5, Alto Monferrato (Southen part), Gavi and Moscato lands; P.7, Langhe e Roero; R.3, Castles of Rome; S.1, Western Sicily; S.4, Etna; T.1, Valdadige of Trentino; U.2, Sagrantino lands and Martani hills; V.2, Valpolicella; V.3, Soave lands; V.6, Conegliano e Valdobbiadene; Z.1, Aosta valley).

Tonietto and Carbonneau, 2004; Jones, 2006; Blanco-Ward et al., 2007). We considered the following bioclimatic indices:

- Mean annual temperature (T);
- Total annual rainfall (P);
- Humidity index (UI), which summarizes the temperature and rainfall trends according to the equation: $UI = P/(T + 10)$;
- Seasonality of the rain (PS), which is the difference between the wettest (Px) and the driest (Pn) month, with respect to annual precipitation (P), as follows: $PS = (Px - Pn)/P$;
- Potential Evapotranspiration (ETo), estimated according to FAO Pennman-Montheith (Perini et al., 2004);
- Continentality index (CI), which represents the temperature range between the average summer temperature (Ts) and the average winter temperature (Tw), as follows: $CI = Ts - Tw$;
- Huglin index (HI), which is a heliothermic index that estimates the cumulative maximum temperature (Tmax) and mean daily temperature (Tmed) in the grapevine growing period. It takes into account a coefficient that is proportional to the length of the day (K) and the vegetative threshold temperature for grapevine (10 °C), as follows:

$$HI = \sum_{30September}^{1April} 1/2 \times [(Tmed - 10) + (T\max - 10)] \times K$$

The climatic layers were created on the basis of 1621 series of long-term mean annual rainfall values (up to 74 years) and 1049 series of long-term mean annual temperature values, referred to 1433 climatic stations (details are reported in Pollini et al., 2013 and Costantini et al., 2013).

As for the soil features which influence grape yield and quality, we privileged those related to water nutrition, since water availability is notoriously considered to be the main soil functional factor in Mediterranean countries (Choné et al., 2001). In particular:

- Clay and sand content, which were averaged for the first 40 cm (CLAY; SAND);
- Depth of pedogenesis (DEPTH), which included horizons A plus B;
- Soil potential water retention at field capacity of the first 50 cm (FC);
- Soil mean annual temperature at 0.50 m (TS50);
- Soil aridity index (SAI), which represents the number of days when the soil is dry in the moisture control section (Costantini and L'Abate, 2009).

In addition, we also considered two components of soil fertility:

- Soil organic carbon stock in the first 0.50 m (CS) (Fantappiè et al., 2010);
- Soil inorganic carbon stock, that is, the lime content in the first 1 m of soil (SIC) (Barbetti et al., 2012).

All the variables were derived from the pedological and geographical information stored in the Soil Information System of Italy (SISI) (Costantini, 2007).

As regard vegetation, NDVI indices were calculated from the MODIS images available at the URL http://modis.gsfc.nasa.gov/. NDVI indices result from the complex interaction between vegetation, climate, terrain, soil, and hydrology (Meirelles et al., 2004; Langella, 2008). Two indices were selected: (i) NDVIS5, which is the sum of the NDVIs during the summer time (from 21 June to 20 September; 5 layers) and may point out the occurrence of an aridity stress, (ii) NDVID16, the maximum difference between the NDVIs of the vegetative period (March-November; 16 layers), which shows the lush increase of vegetation after the winter stasis.

2.3.2. Variables affecting the viticultural management: topographic variables

Viticulture is an agricultural activity which is many times carried out on slopes in Mediterranean countries. Topographic setting may affect crop management and threaten the safety of farmers during mechanized cultivation of vineyards. In general, the higher the energy of the relief and the smaller the valleys and accumulation areas, the harsher the management difficulty of vineyards (Costantini and Barbetti, 2008). Therefore, we estimated the degree of management difficulty by considering the following variables: (i) elevation, obtained from the digital elevation model (DEM at 250 m), (ii) slope, generated from the DEM (SLOPE), (iii) valley size, calculated through Multi-resolution Valley Bottom Flatness index (MrVBF), and (iv) presence of accumulation areas, obtained from the Topographic Wetness Index (TWI).

2.3.3. Variables of environmental context

All agricultural activities, also when conducted in a highly specialized form like viticulture, cannot be isolated from their environmental context, since this last can deeply influence their economic development (Salvati and Zitti, 2005). On the other hand, specialized viticulture in Mediterranean areas are among the activities with the highest impact on the environment, (Martínez-Casasnovas et al., 2009; Dazzi and Lo Papa, 2013). Hence, we considered a set of candidate variables potentially able to highlight the interactions between land quality, intensive viticulture, and land degradation, in particular:

- The Index of land sensitivity to desertification (ESAI), which identifies areas with increasing overall sensitivity to degradation (Basso et al., 2000);
- The soil quality index SQI (Basso et al., 2000), which specifically focuses on soil fragility, and takes into account soil texture, depth, available water capacity, and slope;
- The land vulnerability index to desertification (LVI), suggested by Salvati and Zitti (2009) to appreciate the changes that occurred in climate, land use, vegetation coverage, soil properties, and population amount, during the period 1990–2000.

2.4. Resolution of the geographic layers

The climatic and bioclimatic layers had a resolution of 4 km per pixel, with exception of the variables CI (1 km), PS and HI (500 m). The pedoclimatic and land quality indexes TS50 and SAI had a pixel resolution of 1 km. The layers that derived from DEM and NDVI had a pixel resolution of 250 m, while the soil layers were on a 1 km grid (SIC, CS DEPTH) or they were polygons at 1:500,000 scale (CLAY, SAND). Although the difference in pixel size for the different parameters is rather large, no severe consequences on the elaborations are assumed, since the geographic information was in all cases generalized to the Macroareas level, that is, at the smallest scale (1:500,000).

2.5. Statistical analyses

We used the Statistica software (StatSoft Inc., Tulsa, OK, USA) to run all the statistical tests. Before applying multivariate exploratory techniques, an univariate statistic was carried out to look at the distribution of the main economic and environmental data. Mean, standard deviation and variation index (standard deviation/mean) were calculated. The descriptive statistics showed many violations to the normality assumption, therefore we chose to use multivariate techniques applicable to not normally distributed variables.

The first purpose of the statistical analysis was to reduce the number of variables and discover the hidden variables that have a comprehensive meaning of the total variance. A Principle Component Analysis (PCA) was run to replace the many original variables with few comprehensive variables (called principal components or factors in this work). The analysis was carried out firstly on the economic and then on the environmental data. The new comprehensive variables coming from the PCA of economic data were used to group the Macroareas and highlight WES. The clusters were then related to the principal components of the environmental variables, to look for significant relationships. The main steps of the methodology are reported below and schematically summarized in the data processing flow of Fig. 2.

A) Databases implementation.

The economic database was built up taking into account the data available for the municipalities enclosed within the Macroareas. The mean value and the standard deviation of the environmental variables were calculated for the potential vine growing areas. The standard deviations, in particular, were used to assess the degree of environmental homogeneity within Macroareas. The two datasets were named central tendency database (mean values) and variability database (standard deviations) and they were processed separately in the statistical analyses.

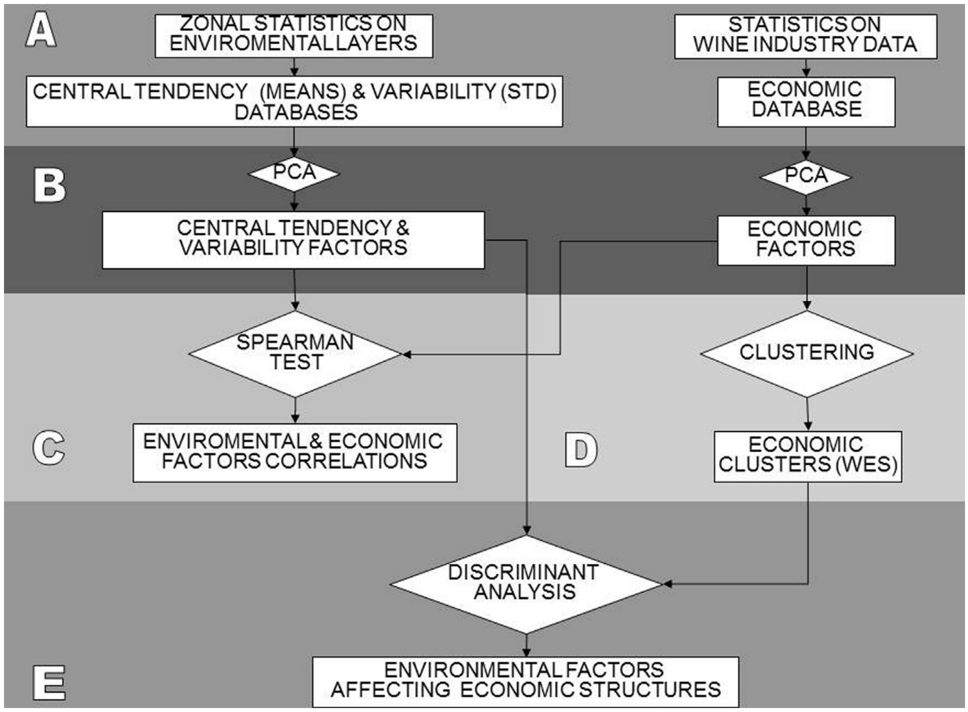

Fig. 2. Data processing flow.

B) Reduction of the dimension of the economic and environmental databases.

The variables that resulted to be strongly correlated (>90%) were removed. Then the variables which could explain at best the overall variability were selected. In particular, the variables were eliminated if they had factorial coordinates <0.5 for a significant factor (factor with an Eigenvalue > = 1). Then the PCA allowed to replace the bulk of original variables with the principal components of the PCA.

C) Correlations between environmental and economic factors.

The correlations between the economic and environmental factors obtained through the PCA were investigated to find which group of environmental features had an influence on the economic characteristic. The non-parametric Spearman test (two lists matrix) was applied to correlate the factor values of the economic components with the factor values of either the environmental central tendency or the environmental variability.

D) Identification of the WES.

A cluster analysis was performed to group the 32 Macroareas. A *k*-Means classification was applied to the coordinates of the economic factors. The number of cluster was chosen so that the variance within the groups was the lowest in comparison with the variance between the groups. The cluster analysis allowed the identification of few groups of Macroareas with common wine economic traits, that is, same WES. Weighted mean values of all the variables were obtained for each cluster in order to have an exhaustive characterization. Contribution of each Macroarea to the final average value of the group was proportional to its surface extension.

E) Environmental drivers of WES.

The economic clusters and the environmental factors were processed through a discriminant analysis. A discriminant analysis allows highlighting the relationship between a qualitative variable (the groups of Macroareas belonging to the same WES) and a set of determinant quantitative variables (the environmental factors) (Bouroche and Saporta, 1980). A Wilks' lambda test was carried out to express the portion of variance that was not reproduced by the division in group. Its value could range from 1.0 (no discriminatory power) to 0.0 (perfect discriminatory power). The F-remove test was also run to assess, the higher the better, the decrease in discrimination due to the removal of a variable. It is a partial multivariate F statistic that can be used to obtain the rank order of the unique discriminating power carried by each variable (Klecka, 1980).

The expected outcome of the procedure was the possibility to highlight the environmental factors that result to discriminate and characterize each group of Macroareas; they ought to be considered the environmental drivers of the different WESs.

3. Results

3.1. Principal component analysis

Tables 1–3 report the results of PCA and show that the bulk of economic data can be summarized in five factors, which together explain 83.5% of the total variability. The biophysical properties of Macroareas instead are characterized by two models, one related to the central tendency database and the other to the variability database. In the first model, three factors explains the 74.9% of the total variability, whereas in the second five factors sum up 64.9% of the variability.

3.1.1. Economic factors of the Macroareas

The selected five economic factors are characterized by different set of variables that allow distinguishing distinct targets of viticultural results, wine production quality, and winery dimension, as follows:

- The dominant variables for Factor 1 (Fact1_vit) are the presence of independent farms (IFn 0.780; IFS 0.791), the DOP production in little farm wineries (DOP% 0.797; CWm −0.831; AGR% 0.851) and the low total production of both grape and wine (GPm −0.494; WP −0.843);

Table 1
Factorial coordinates of the economic variables.

	Fact1_vit	Fact2_vit	Fact3_vit	Fact4_vit	Fact5_vit
Cumulative variance explained (%)	38.4	56.2	69.4	77.2	83.5
WP	−0.843	−0.093	0.271	0.212	−0.193
VS	−0.728	−0.174	0.138	0.284	−0.469
VSm	0.032	−0.936	0.187	−0.083	−0.110
NW	0.234	0.285	0.347	0.262	−0.617
CWm	−0.831	−0.174	−0.006	0.227	0.030
GPm	−0.494	−0.635	0.374	−0.089	0.279
DOP%	0.797	−0.190	−0.203	0.395	−0.021
IGP%	−0.384	−0.163	−0.410	−0.687	−0.146
TAB%	−0.604	0.341	0.547	0.085	0.137
AGR%	0.851	−0.345	−0.003	0.042	−0.081
COOP%	−0.771	0.218	−0.451	−0.056	−0.133
IND%	−0.220	0.243	0.745	0.019	0.359
IFn	0.780	−0.136	0.448	−0.177	−0.100
IFS	0.791	−0.200	0.451	−0.193	−0.083
IFSm	−0.279	−0.899	0.046	−0.062	−0.165
Pv%	−0.553	0.167	0.368	−0.499	−0.187
Ev%	−0.397	−0.543	−0.216	0.331	0.280

Table 2
Factorial coordinates of the environmental central tendency data.

	Fact1_m	Fact2_m	Fact3_m
Cumulative variance explained (%)	38.4	59.8	74.9
T_m	−0.931	−0.190	−0.086
P_m	+0.674	−0.170	−0.298
CI_m	+0.759	+0.543	−0.010
PS_m	−0.616	−0.643	−0.078
HI_m	−0.866	−0.027	−0.296
NDVIS5_m	+0.933	−0.076	−0.031
DEM_m	+0.183	−0.355	+0.696
MrVBF_m	−0.355	+0.145	−0.760
TWI_m	−0.172	+0.145	−0.826
SAND_m	+0.010	−0.891	−0.096
FC_m	−0.382	+0.857	+0.132
DEPTH_m	+0.169	+0.602	−0.199
CS_m	+0.684	−0.211	−0.595
SIC_m	−0.229	+0.711	+0.207
SAI_m	−0.887	−0.011	+0.142
ESAI_m	−0.754	+0.199	+0.029

- Limited grape yield (GPm −0.635), table wine production (TAB% 0.341) and the ratio of existing vineyards on potential wine growing area (Ev% −0.543) dominate Factor 2;
- Presence of farms conferring grape to the industry for table wine production and absence of cooperative wineries (IND% 0.745; COOP% −0.451; TAB% 0.547) are the characterizing variables of Factor 3 (Fact3_vit);
- The dominant variables for Factor 4 (Fact4_vit) are low IGP production (IGP% −0.687) and limited potential grapevine surface (Pv% −0.499);
- Low presence of wineries and of total vineyard acreage (NW −0.617; VS −0.469) qualify Factor 5 (Fact5_vit).

3.1.2. *Environmental factors of Macroareas*

The main environmental features of the studied Macroareas are summarized in three factors related to the central tendency values and in five factors related to their variability.

Central tendency values:

- Several climatic, land quality, and soil variables dominate Factor 1 (Fact1_m). High values point to areas with low mean annual temperature, low Huglin index, but large annual temperature excursion (T_m −0.931; HI_m −0.866; CI_m +0.759); large annual precipitation, distributed all over the year (P_m +0.674; PS_m −0.616); low desertification and aridity indices, lush vegetation in summer, and high soil organic carbon content (ESAI_m −0.754; SAI_m −0.887, NDVIS5_m +0.933, CS_m +0.684);
- Main variables that qualify Factor 2 (Fact2_m) regard soil properties. In particular, presence of fertile, deep soils (DEPTH_m

Table 3
Factorial coordinates of the environmental variability data.

	Fact1_std	Fact2_std	Fact3_std	Fact4_std	Fact5_std
Cumulative variance explained (%)	25.8	42.4	57.3	66.1	73.7
T_std	+0.760	+0.198	−0.259	−0.040	+0.049
P_std	+0.665	−0.131	−0.517	−0.297	+0.050
CI_std	+0.654	−0.112	+0.175	+0.093	+0.147
NDVIS5_std	+0.628	+0.221	+0.088	+0.106	−0.609
NDVID16_std	+0.449	+0.161	+0.326	+0.018	−0.705
DEM_std	+0.599	−0.591	−0.027	−0.119	+0.185
SLOPE_std	−0.195	−0.854	−0.233	−0.036	−0.205
TWI_std	+0.000	−0.779	−0.199	−0.234	−0.093
CLAY_std	+0.285	−0.211	+0.667	−0.546	+0.075
SAND_std	+0.222	−0.293	+0.618	−0.463	+0.050
FC_std	+0.374	+0.107	+0.742	+0.031	+0.068
CS_std	+0.241	−0.632	−0.084	+0.381	−0.032
SIC_std	+0.629	−0.011	+0.138	+0.408	+0.452
TS50_std	+0.618	+0.421	−0.428	−0.191	+0.001
SAI_std	+0.534	+0.191	−0.579	−0.394	+0.016
ESAI_std	+0.601	+0.128	+0.188	+0.307	+0.214
SQI_std	+0.432	−0.481	−0.039	+0.460	−0.210

Table 4
Clusters of Macroareas showing common WES.

A	B	C	D	E	F
Soave lands	Vulture	Castles of Rome	Chianti Classico	Eastern coast	Hills of Romagna
Valdadige of Trentino	Ionian Crotone zone	Salento area	Franciacorta and hills of Brescia	Central hills (Marches)	Adriatic coast zone
Valpolicella	Sannio	Friuli Grave	Oltrepò Pavese	Alto Monferrato (southen part), Gavi and Moscato lands	Bari lands
	Molise	Lambruschi of Emilia lands	Montalcino and lands of Siena	Valtelline	Western Sicily
	Gallura	Conegliano e Valdobbiadene	Eastern hills of Friuli	Langhe e Roero	
	Sagrantino lands and Martani hills		Bolgheri and Etruschi coast	Irpinia	
	Etna			Aosta Valley	

+0.602), not sandy (SAND_m −0.891), with a high field capacity (FC_m +0.857) and a high inorganic carbon stock (SIC_m +0.711). In addition, low rain seasonality (PS_m −0.643) and the presence of wide annual temperature excursions (CI_m +0.543) characterize Factor 2;
- Morphological variables are summarized in Factor 3 (Fact3_m), which highlights conditions of rough morphology, high elevation and slope (DEM_m 0.696; TWI_m −0.826; MrVBF_m −0.760) with high frequency of degraded soils (CS_m −0.594).

Environmental diversity:

- High standard deviations of several variables qualify Factor 1 (Fact1_std), namely climate, pedoclimate, lush vegetation (T_std 0.760; P_std 0.665; CI_std −0.654; TS50_std 0.618SAI_std 0.534, ESAI_std 0.601; NDVIS5_std 0.628), as well as elevation (DEM_std 0.599), and inorganic carbon stock (SIC_std 0.629);
- Low variations of morphological variables dominate Factor 2 (Fact2_std) (SLOPE_std −0.854; TWI_std −0.779; DEM_std −0.591), likewise organic carbon stock and desertification risk (CS_std −0.632; SQI_std −0.481);
- High values of standard deviation of pedological variables characterize Factor 3 (Fact3_std) and thus the territories with irregular textural and available soil water at field capacity (CLAY_std −0.667; SAND_std 0.618, FC_std 0.742), but uniform values of aridity index and precipitation (P_std −0.517; SAI_std −0.579);
- Factor 4 (Fact4_std) is proportional to the homogeneity of soil texture (CLAY_std −0.546; SAND_std −0.463). However, as it did not add information to Fact3_std, it was not taken into account in the next statistical analysis;
- The homogeneity of both vegetation indices (NDVIS5_std −0.609; NDVID16_std −0.705) are expressed in Factor 5 (Fact5_std).

3.2. The cluster analysis: outlining WESs

The cluster analysis of the economic factors allows forming 6 groups of Macroareas, sharing common viticultural and wine production features, that is, same WES (Table 4). The variance analysis points out that all five factors of the PCA are able to separate at least one group (Fig. 3), but Factor 1 has the strongest diversifying power, followed by Factor 2 and 4. In fact, the three factors have variance values within groups lower than between groups (Factor 1: between variance 169.5, df 5; within variance 32.9, df 26; F 26.73; Factor 2: between variance 69.5 df 5; within variance 24.2, df 26; F 14.91; Factor 4: between variance 27.1, df 5; within variance 14.1, df 26; F 9.96; p level <0.001).

3.3. Correlation between environmental and economic factors

The statistical analysis carried out with the Spearman test points out the most significant relationships between the environmental drivers and the economic features. In five cases the relationship is statistically significant (Tables 5 and 6). On the other hand, some environmental factors do not have correlation with any economic factors, namely, Factor 1 of central tendency and Factor 3 of variability.

Table 5
Correlation between economic and environmental central tendency factors (Spearman test: ***p level < 0.01; **p level < 0.02).

	Fact1_m	Fact2_m	Fact3_m
Fact1_vit	+0.231	−0.443**	+0.095
Fact2_vit	−0.202	−0.093	+0.470***
Fact3_vit	−0.173	+0.178	+0.116
Fact4_vit	+0.345	−0.136	+0.248
Fact5_vit	+0.303	−0.236	−0.129

Table 6
Correlation between economic and environmental variability factors (Spearman test: ***p level < 0.01; *p level < 0.06).

	Fact1_std	Fact2_std	Fact3_std	Fact4_std
Fact1_vit	−0.136	−0.055	−0.208	−0.341*
Fact2_vit	+0.457***	−0.192	+0.006	−0.081
Fact3_vit	+0.275	+0.022	+0.109	+0.106
Fact4_vit	+0.069	−0.514***	−0.060	−0.203
Fact5_vit	−0.319	−0.274	−0.003	+0.077

3.4. Discriminant analysis

The discriminant analysis unveils that environmental factors that differentiate WESs. In particular, both environmental variability (Wilks'Lambda = 0.18355; F (20,77) = 2.5765 p < 0.0016) and environmental central tendency (Wilks'Lambda = 0.17047; F (15,66) = 3.9912 p < 0.0001) result to play a discriminating role on WESs. The greatest contributions to the discrimination are given by Factor 2 of environmental variability and Factors 1 and 3 of environmental central tendency.

4. Discussion

4.1. Economic and environmental features of the Macroareas

The first economic factor of the PCA identifies Macroareas of premium vine cultivation, where little independent wineries produce little quantities of wine with high quality and economic value. In addition, Factor 1 depicts an orientation of the wine transformation industry towards a vertically integrated structure. The collective reputation, based upon a restrictive disciplinary, a strong relationship with the territory, and a close relationship with the consumers (short supply chain) favor the farmers on the wine market.

Factor 2 characterizes Macroareas with a relatively lower intensity of production activity and quality of wines. In these Macroareas, there is a low attitude toward the DOC production, whereas table

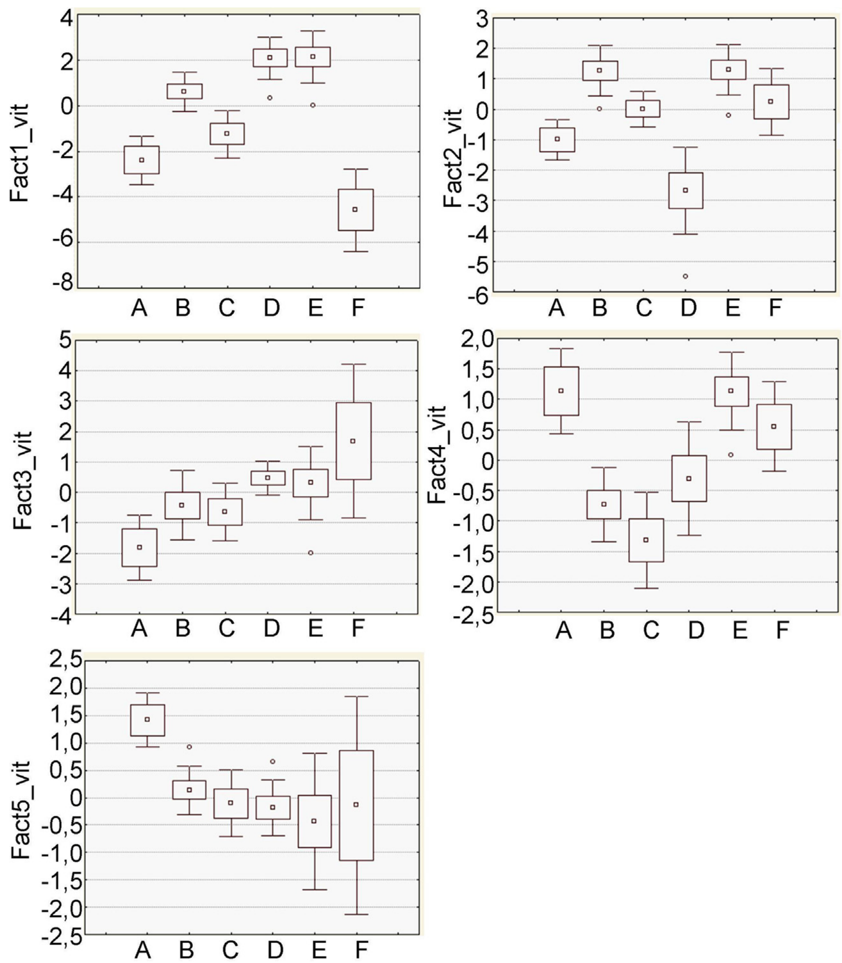

Fig. 3. Box plots of the 5 economic factors for the 6 clusters. Mean values (middle point), standard error (box value), standard deviation (whisker value) and outliers.

wine production is widespread. There is a strong presence of industrial and cooperatives wineries to the detriment of the integrated ones. Many not independent small farms confer their grapes to the cooperatives wineries.

Factor 3 points to Macroareas where viticulture is particularly oriented to the massive production of relatively lesser quality wines. The production systems are characterized by a high incidence of industrial wineries that produce for the intermediate market. The trend is confirmed by the little presence of small independent farms and of premium quality wines.

Factor 4 groups Macroareas suited both to quality and quantity production, but not showing a well definite WES, since wineries do not have IGP wine as target, and the territory suitable for viticulture is limited.

The fifth factor indicates Macroareas with limited vine cultivation suitability. This factor points to territories of current marginal interest to viticulture.

As for the PCA of environmental features, Factor 1 identifies Macroareas of non-Mediterranean climate, without a pronounced summer drought. Because of the temperate climate, relatively high soil organic matter contents are maintained. Factor 2 points to Macroareas with good soil hydrological qualities. Factor 3 qualifies Macroareas whose limitations are related to the difficult morphological conditions.

Factor 1 of environmental variability indicates wide uneven areas, encompassing many different climatic as well as pedological conditions, whereas Factor 2 is related to areas where there are uniformity of morphological and soil quality conditions. Factor 3 highlights territories with heterogeneous soil conditions and Factor 5 shows the homogeneity of vegetation lushness in the Macroareas, both in summer and in the whole vegetative period.

4.2. Common features within Macroareas clusters

The economic and environmental clusters are well characterized and distinguished for the average, standard deviation and median of economic factors, as well as for the weighted mean of environmental and economic variables. Cluster A groups Macroareas located in the Alps and Prealps (Fig. 4). They are territories with severe limitations for agriculture, which confine wine exploitation to marginal lands (so-called "heroic viticulture"). Small territories, with high grape suitability, which are already fully exploited for their wine potential. In fact, Macroareas of the cluster show limited vineyard coverage, few wineries (small values of Fact5_vit; mean NwF = 3902; mean NW = 175), a large amount of surface not suitable for wine growing (small values of Fact4_vit; mean Pv% = 31.2), but high wine quality (small values of the Fact3_vit; mean DOP% = 0.587, IGP% = 0.323 and TAB% = 0.090).

Cluster B is formed by Macroareas with small farms (mean VSm 1.77 ha), low average production of grapes (GPm 16.6 Mg), and small wineries (mean CWm 418 ha), which produce DOC wines, table wine and IGP (high value of Fact2_vit, medium-high of Fact1_vit, low Fact4_vit; mean DOP% 0.455, IGP% 0.289 and TAV% 0.266). Although the acreage of the potential wine producing area

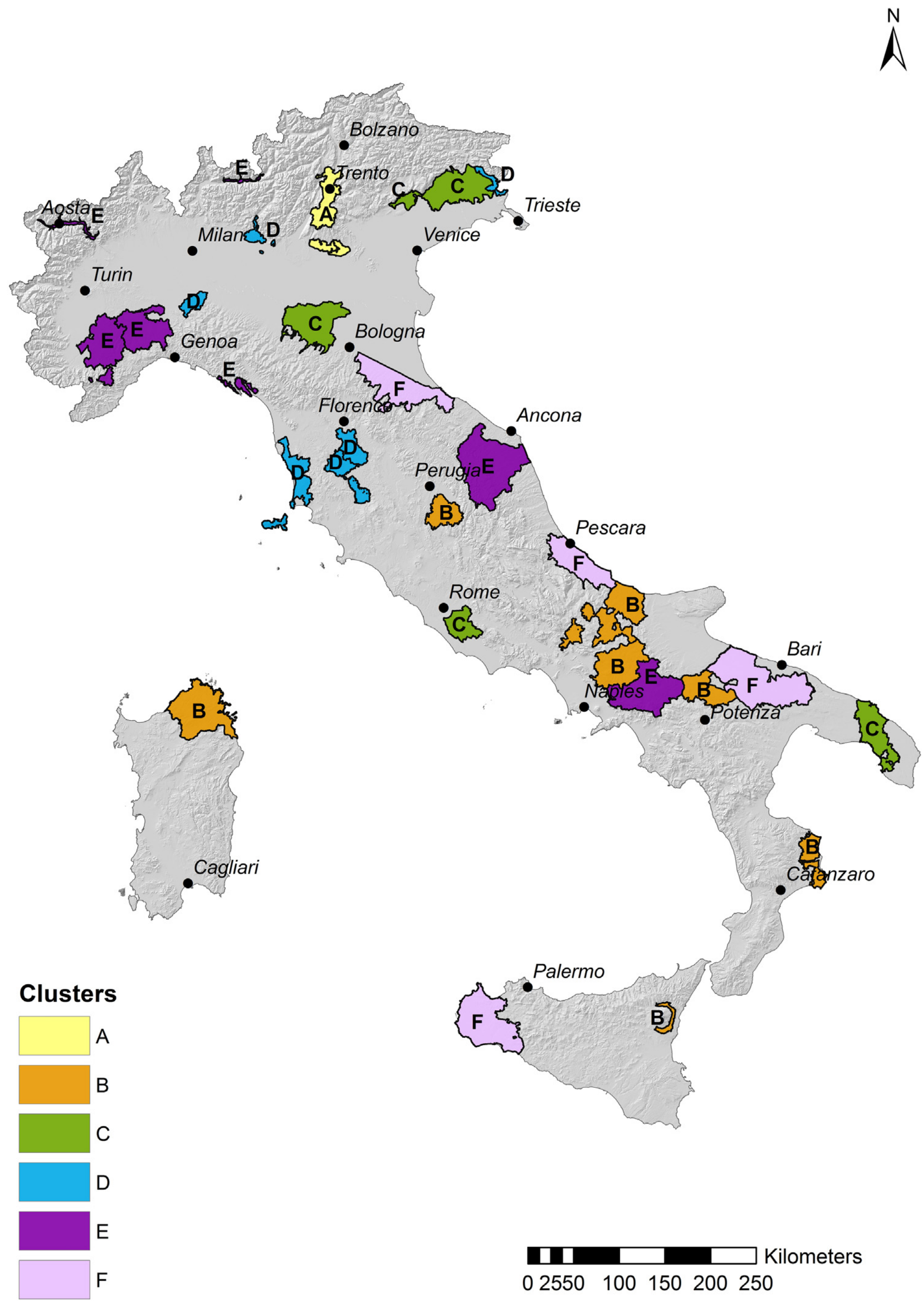

Fig. 4. Map of the viticultural Macroareas showing common WES.

is relatively high (low Fact4_vit; mean Pv% 62.4), the areas are still scarcely planted with vineyards (mean Ev% 2.2), then vine cultivation has a good possibility to develop further. Representative areas of this group are spread on the reliefs of center and south Italy. The climatic conditions are suitable for good viticulture, but the rough topography limits farm dimension. The ratio of the land covered by vineyards on the area that is potentially suitable is low, which means that viticulture is not the dominant crop, although the Macroareas have good viticultural potentialities.

Cluster C groups Macroareas that mainly produce IGP (low Fact4_vit; mean IGP% 0.492), in wide surfaces with good potential viticultural suitability (low Fact4_vit; mean Pv% 80.9); they show a little prevalence of cooperatives on autonomous farms (mean IFn 0.388; mean COOP% 0.654). Representative areas of this group are located all along the peninsular Italy. They share many morphological and pedological conditions; in particular, they have rather fertile soils, allowing both good quantity and quality of grape production.

Cluster D refers to Macroareas widely suited to the vine growing and well valued by products of excellence. Farms show strong environmental characterization and a consolidated viticultural tradition of renowned DOCG. They are large independent farms with a big grape production (mean IFn 0.991; mean IFSm 5.591). Small wineries produce DOC wine (high Fact1_vit, low Fact2_vit; mean CWm 427 ha; mean DOP% 0.659). Representative areas of this group are placed in the north-central Italy, namely the gentle hills of Tuscany, Pre-Alps and Pre-Apennines.

Macroareas of cluster E are characterized by small independent farms (high Fact2_vit; mean IFn 0.811; mean IFSm 1.679) that produce DOC wine, but with low quantities (low Fact1_vit; mean DOP% 0.713; mean GPm 13.5 Mg). The IGP production is very small (high Fact4_vit; mean TAB% 0.105). The areas not suited to viticulture are relatively abundant (high Fact4_vit; mean Pv% 60.4). They are lands with high energy of relief, which limits the spread of vine cultivation, but the wine production is of high quality. Many representative areas of this group are located along the Pre-Apennines and two of them in the valleys of the Alps. Because of the topographic difficulties, farms with little dimension are prevalent, the production is limited, but the wine quality is very high.

Macroareas of cluster F show wide and homogeneous lands, with large surfaces covered by vineyards and very large productions of wine (low Fact1_vit; mean WP 4,142,194 hl; mean VS 32,435 ha). The economic structure is characterized by industrial wineries that produce table wine (high Fact3_vit; mean IND% 0.534; mean TAB% 0.675). The wineries show high production capacity (low Fact1_vit; mean CWm 8749 ha). Representative areas of this group are placed on the low hills along the Adriatic coast and on the northwest coast of Sicily. The absence of strong morphological limitations, the high soil fertility, and the presence of suitable Mediterranean climatic conditions allow the development of a WES type dominated by wide companies, targeted to a wide-scale production business. Opposite to the D group, the tendency of the enterprise is toward a “long supply chain”, with many passages between producer and final consumer.

4.3. Environmental drivers of WES

The statistical correlation between economic and environmental factors highlights some significant relationships:

a.) The inverse correlation between economic Factor 1 and environmental Factor 2 (Spearman = 0.443, $p<0.02$) demonstrates that an excellent production fits well with a rather low water availability, due to both soil and climatic limitations. This relationship, which was already well documented at the terroir detailed scale (Van Leeuwen et al., 2004), is confirmed by this study also for the scale of large viticultural territories and the areas with Denomination of Origin.

b.) The Macroareas with low intensity and relative lower quality of wine production have significant relationships with limitations given by the rough topographic conditions and large climatic and pedoclimatic variability. In particular, the economic Factor 2 is correlated with Factor 3 of the environmental mean characteristics (Spearman = +0.470, $p < 0.01$) as well as with Factor 1 of variability (Spearman = 0.457 $p < 0.01$).

c.) The inverse correlation between economic Factor 4 and Factor 2 of environmental variability (Spearman = 0.514 $p < 0.01$) suggests that Macroareas showing heterogeneous soil and morphological conditions lack a well-defined tendency in the economic choices.

The discriminant analysis separates three broad WESs, which are distinguished by the average values more than by the variability of environmental factors. Thus the mean environmental characteristics seem to have a major impact on the long-term economic choices of wine producers.

5. Conclusions

The multivariate type of analysis allows some generalizations about the relationships between the environmental drivers and the types of WES of Italy, which go beyond the classical differentiation between north, center and south of Italy. In particular, the six groups obtained from the economic clustering of the Macroareas point to the identification of three main different systems of wine production and organization. A first WES, typical of Macroareas of cluster F, features industrial wineries of medium-large dimension, mainly oriented to the production of table wine, and characterizes large territories of big wine grape production. The producers are targeted at pursuing scale economies and developing strategies for large volumes of wine. They have flexibility and can diversify the product according to the tendencies of the market.

A second main WES characterizes farms that are oriented to high quality wines. They base their competitiveness on the participation to wine consortia and collective marks. The level of reputation and recognition is based upon the strong linkage between DOC and territory. This WES typifies Macroareas of cluster D. These Macroareas are well environmentally delimited and well suitable for viticulture. Their valorization takes place through the excellent of their products. This tendency also distinguishes cluster E but here, unlikely cluster D, the excellence is pursued by little farms, because of the environmental limitations to vine cultivation. Cluster A can be assimilated to the former, as for the wine quality production, but the main economic structure here is the cooperative. Moreover, cluster A groups Macroareas where viticultural potentialities are already fully exploited.

A third main WES is characterized by the coexistence of different productive conditions. The system is formed by cooperative wineries which have a high diversification in terms of the quality of the products. Macroareas of groups B and C belong to this system.

The discriminant analysis points out that different WESs are mainly separated by the mean values of the environmental drivers of Macroareas. This would suggest that farmers working in similar environmental contexts are led towards similar viticultural and oenological economic choices. The most discriminating environmental factors are average climatic and pedoclimatic parameters, followed by variability of morphological conditions.

The correlations between economic and environmental factors stresses that environmental variability within a viticultural district is a cause of weakness for the wine economic structure. Specifically, the relationship highlights that where the environmental characteristics are variable, the firms also tend to diversify for both the kind of wine and the organization form of production. This conclusion would suggest to carefully consider environmental characteristics and variability, when creating a new area with a Denomination of Origin. In other words, the selection of the size area to delimitate a Denomination of Origin, encompassing territories with different environmental characteristics and variability, affects the type of viticulture and wine production that will be obtained.

The multivariate statistical approach presented here demonstrates to be able to discover the hidden relationships between the economical dimension of wine production and the characteristics of the environments where vineyards are planted and different kinds of wine are produced. Similar methodological approaches might be conducted in other countries or at different territorial scales, so to highlight both potentialities and physical constraints of viticultural lands and improve the land planning of different wine production systems. Similar approaches could be also applied to other quality crops, like olive oil, coffee, or cheese production, which show the terroir effect (Costantini and Bucelli, 2014)

Finally, the results of this research work stress how important are environmental characteristics in addressing the economic structure of wine production in a territory. This fact should encourage farmers and all stakeholders to a better knowledge and a careful care of land qualities of viticultural areas.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2016.05.015.

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