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A mix-method model for adaptation to climate change in the agricultural sector: A case study for Italian wine farms

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ABSTRACT

The negative effects of climate change are predicted to impact the agricultural sector in coming decades. Economic losses and modifications of production processes are fundamental issues to consider in coping with the harmful consequences of climate variability. The literature and empirical evidence show that the wine sector is extremely vulnerable to this risk. These studies show that this sector lacks appropriate adaptation strategies due to the complexity of the analysed systems and interrelations between a number of socio-economic and environmental variables. The present study designed a decision support system to identify adaptation strategies for wine farms undergoing climate change. The tool allows for the analysis of a wine farm's economic performance when it adopts measures to cope with climatic variability. Average values for climate change and extreme events were considered to assess different scenarios. A mix-method approach was applied to integrate probability calculations, complex system analyses and operational research (a metaheuristic approach). The model was tested on a case study located in central Italy (Chianti Classico). To maintain and improve future financial performance, organic farming and adjustments to procedural guidelines were recommended as key strategies. Economic variables, such as the average price of wine, seem to have a strong influence on farms' implementation of adaptive measures. An additional result seems to suggest that insurance schemes in areas producing high quality wine are only suitable when low-level deductibles and public funding are available. The present work shows that the decision support system favours analytical sensitivity to different scenarios and variables related to climate change as well as to socio-economic shifts in the viticulture sector.

1. Introduction

Climatic change is forecast as a major phenomenon in short- and long-term projections of Intergovernmental Panel on Climate Change (IPCC, 2014). The predicted variability is mainly associated with an increase in average temperature and decrease in average precipitation. These aspects are also combined with a high likelihood for the intensification of extreme events such as drought, particularly in Europe (Collins et al., 2013). This framework stresses the need for appropriate actions to cope with the risks related to climate change, taking into account the scale of analysis and local features (Mirzabaev et al., 2015).

Rural areas appear particularly susceptible to climate change due to harmful impacts on important economic and social dynamics (Dubey et al., 2016) and environmental and land-use trends (Dasgupta et al., 2014). As stated in IPCC (2014), "the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure […]" (pag. 124). The wine industry, a rural sub-sector, is also at risk for substantial climatic-related threats (Schultz and Jones, 2010). The primary negative effects of climate change on the wine industry are potential losses to product quantity and quality. Additional risks are related to consequences on revenues and production costs throughout the supply chain (Mozell and Thach, 2014). The modification of production processes due to climate variability and extreme events may lead to additional socio-economic impacts for the whole sector and its related activities (Pomarici and Seccia, 2016).

Researchers have made several attempts to identify adaptation

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Nomenclature

AS_i	dummy variable referred to *i-th* adaptation strategy, that can be 1 if activated, 0 otherwise. AS_i can be: AS_n anti-hail net, AS_o organic farming, AS_g organic farming + certification, AS_f fans, AS_h heater/candles, AS_u under/over canopy irrigation, AS_c cultivar substitution, AS_r fixed irrigation plant, AS_e emergency irrigation, AS_d procedural guidelines modification, AS_t increase of phytosanitary treatments, AS_s insurance
C_i	cost per each φ category (€/ha y^{-1})
d_e	level of damage for *e-th* extreme events (%) where *e* can be: *F* frost, *N* hail, *H* heat waves, *D* drought, *T* phytopathologies
DEN	dummy variable: 0 if Controlled and Guaranteed Designation of Origin (DOCG) certification is not present, 1 otherwise
e	extreme event category where *e* can be: *F* frost, *N* hail, *H* heat waves, *D* drought, *T* phytopathologies
I	intercept of VQ_f equation
LAN	dummy variable: 0 if landscape constraint is not present, 1 otherwise
m	number of extreme event categories
n	number of cost categories (related to wine production process)
NR_c	current net revenues (€/ha y^{-1})
NR_f	future net revenues (€/ha y^{-1})
ORG	dummy variable: 0 if certification for organic practices is not present, 1 otherwise
$P(e)_c$	current probability of *e-th* extreme event occurrence defined as in Table 1 (%)
$P(e)_f$	future probability of *e-th* extreme event occurrence defined as in Table 1 (%)
p_A	base price for bulk wine (€/l)
p_B	base price for bottled wine (€/l)
p_α	final price of bulk wine (€/l)
p_β	final price of bottled wine (€/l)
T_{sum}	average temperature in the summer period (°C)
VQ_c	current vintage quality rating of wine
VQ_f	future vintage quality rating of wine
Y_c	current wine production calculated with the growth simulator model of Bindi et al. (1997) and updated in Bindi et al. (2005) (l/ha y^{-1})
Y_f	future wine production calculated with the growth simulator model of Bindi et al. (1997) and updated in Bindi et al. (2005) (l/ha y^{-1})
Z_{mat}	precipitation in the anthesis-maturity period (mm)
α	percentage of bulk wine (%)
γ *and* δ	coefficients of VQ_f equation
ε_{VQ}	price elasticity in respect to wine quality. Derived from average value in Neill (2011) and Abraben (2014)
θ	indemnity (€/ha y^{-1})
λ	influence of certification of organic practices on wine price (%). Derived from Abraben (2014)
φ	cost category (see section 2.2. for more details)
χ	deductible (%) for insurance schemes
ω	influence of DOCG certification on wine price (%). Derived from Contini et al. (2015)

strategies and policies to address the harmful consequences of climate change on the wine industry. Most studies focus on the first step of the production process (field phase) showing a predominant interest in water deficit contrast (Sacchelli et al., 2016). Costa et al. (2014) presented a strategy to promote water efficiency and sustainable water use and to minimise environmental impact in southern Europe's wine sector. Nicholas and Durham (2012) conducted interviews to observe farm-scale adaptive responses to climatic stress and to comprehend the motivations and views of agricultural managers in California. A further study focused on adaptive capacities for aesthetic logic – aligned with environmental sustainability and mitigation – and market logic to promote adaptation to localised impacts in Australia (Fleming et al., 2015). Lereboullet et al. (2013) considered suitable socio-ecological adaptation measures for two case studies (Roussillon – France and McLaren Vale – Australia) and evaluated the economic performance of adaptive actions from different perspectives. Hadarits (2011) introduced the concepts of adaptive strategies and adaptive capacity and their influence on economic performance of wine farms in Maule region (Chile). De Salvo et al. (2015) paid particular attention to winegrower education, farm technology and winegrowers' awareness of climate change's impacts to cope with these effects in the Moldavia region's (Romania) wine industry. Bernetti et al. (2012) assessed the "adaptation probability" according to professional training, specialisation and capacities to react to unexpected situations among farmers in the area of Brunello di Montalcino (Italy). A recent study measured the financial efficiency of vineyard relocation and the adoption of drought-resistant grape varieties in the Chianti region (Italy) (Zhu et al., 2016).

The above literature review suggests that the high territorial peculiarity and differentiation of local wine-growing contexts – well explained by the *terroir* concept (Clingeleffer, 2014) – hinder the development of generalisable models. These problems are manifest in researchers' projection of suitable adaptation strategies and depictions of farmers' intentions to adapt to climate change in the medium- to long-term (Arunrat et al., 2017). Snyder et al. (2011) stated that the assessment of climate change impacts is often "disciplinary-based and not sufficiently integrative across important disciplinary subcomponents, producing misleading results that have potentially dangerous environmental consequences" (pag. 467). A further issue is the need to introduce the complexity of the analysed systems to facilitate readiness, communication and potential applications for research outputs (Serrao-Neumann et al., 2015). This last aspect is particularly important in the case of medium- to long-term scenarios and the involvement of non-expert stakeholders who may perceive the analysed issues as vague and ambiguous (Dulic et al., 2016).

The combination of methods and tools in climate change impact analysis creates a need for procedures that can represent the "wine system" as a structure with non-continuous, reflexive and emergent characteristics. These parameters can be addressed with the concept of "complex systems" (Sayama, 2015). As reported in Chapman (2009), there is no agreement upon definition of complexity, but the presence of non-continuous interactions (i.e. when a change in one variable does not cause a proportionate constant change in a dependent variable) could be considered as the most important characteristic. Chapman states how "the single parameters of a system have a cognitive model of their role and position in the system, but because these cognitive models cannot claim to have complete knowledge of themselves or the system, the partiality of knowledge is the reason that the characteristic behaviour of the whole is seen to be emergent" (Chapman, 2009;