Adapting the wine industry in China to climate change: challenges and opportunities

Yuanbo Li and Isabel Bardaji*

Departamento de Economía Agraria, Estadística y Gestión de Empresas, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, Av. Puerta de Hierro, 2, 28040, Universidad Politécnica de Madrid, Spain

This article is published in cooperation with the ClimWine international conference held in Bordeaux 11-13 April 2016. Guest editor: Nathalie Ollat

Abstract

Recently, China has become an exciting wine consumer market and one of the most important wine producers. China’s domestic wine industry is in the enviable position of contributing approximately 70% of the total wine consumed with a 1.36 billion population market and the second largest world economy. Current studies of the Chinese wine industry are mostly focused on the wine market. However, global climate change, which affects the quantity, quality and distribution of wine, will have a strong impact on the Chinese domestic wine industry. In this paper, we characterize the impact of climate change in China and establish policy, financial, technical, institutional and collaborative adaptation strategies for the Chinese wine industry.

Key words: climate change, wine industry, China, adaptation strategies
INTRODUCTION

Global warming is a common challenge for society. The Intergovernmental Panel on Climate Change (IPCC) report presents that increasing mean surface air temperatures over oceans and land have been observed over the last century (IPCC, 2013). Additionally, in several regions of the world it is evident that climate change has affected both terrestrial food production and crop yields (IPCC, 2014). Under climate change, especially in developing countries, such as China, agriculture is the most vulnerable economic sector (Chen S. et al., 2016).

A widespread observation is that climate change will affect both the geographical distribution of the wine industry and the quality of the product. Although wine is not an essential agricultural product for survival, it is closely connected to human history and culture as a significant product of human ingenuity (Mozell and Thach, 2014). Viticulture contributes to the local economy, tourism, industry and natural habitat (Duchene, 2016; Resco et al., 2016). In recent years, China has joined the world’s wine world presenting significant suitable regions and diverse climatic sites (De Orduña, 2010; Hannah et al., 2013). A great expansion of Chinese domestic wineries in new regions with increasing capability may be observed (Mozell and Thach, 2014). While there have been continued improvements in the wine industry, it is necessary to recognize the impact of global climate change, which will bring both challenges and opportunities to China.

In this paper, we review the development of the Chinese wine industry and explore how climate change will affect viticulture and the Chinese wine industry. Next, we provide climate change adaptation strategies for the wine industry in China.

MATERIALS AND METHODS

In this study, we use secondary data collected from the International Organization of Vine and Wine (OIV) and the National Bureau of Statistics of China, the China Sugar and Liquor Yearbook, Chinese business information networks and literature review to examine the development of the wine industry in China.

To better understand how climate change will affect the global wine industry, we explore the structural relationship between climate change and vineyards. We attempt to analyze the possible benefits (opportunities) and harms (challenges) of climate change for the Chinese wine industry based on a number of indicators of both climate variables (temperature, accumulated heat, precipitation, water resource, and frost-free period) and climate events (drought, flood, extreme rainstorm, fog, and hail). For the whole country, secondary data are mainly obtained from three sources: 1. Literature review of studies in China; 2. Institutes and organizations, such as the China Meteorological Administration, the National Bureau of Statistics of China and the World Bank; and 3. Government reports and bulletins, such as the Ningxia Statistical Yearbook and the China Flood and Drought Management. For the primary wine-producing provinces, qualitative analyses are made by literature review of Chinese studies.

WINE INDUSTRY IN CHINA

China has a 6,000-year history of grape growing and a 2,000-year history of wine making (Qiu et al., 2013). The Chinese wine history can be traced back to the Han Dynasty when wine was introduced from central Asia. Grapes were planted and wine was produced in the Yellow River region in the northeast (Liu F. and Murphy, 2007). The first Chinese company, Changyu, was established in 1892 in the coastal city of Yantai in Shandong Province (Mitry et al., 2009).

Regionally, China has a large geographical size and distinct topographical situations including grassland areas and semi-arid plateau in the north, oasis and deserts in the northwest, semi-humid basin in the center, forests and plains in the northeast, high-altitude plateau in the southwest and humid coastal areas in the southeast. Vineyards for wine making are widely distributed across the Chinese territory and face a variety of geographical and climatic conditions (Figure 1). The main wine-producing provinces are Xinjiang, Yunnan, Henan, the Central Region including Ningxia, Gansu and Shaanxi, the Bohai Bay Region including Shandong, Hebei and Tianjin, and the Northeast Region including Liaoning, Jilin and Heilongjiang. The Yantai Region of Shandong (1987) and the Ningxia Hui Autonomous Region (2012) are involved with the OIV as observers. Cabernet Sauvignon is the most widely planted wine grape in China with more than 20,000 ha followed by Chardonnay, Cabernet Franc, Syrah, and Pinot (Li H., Li and Yang, 2009).

China’s domestic wine production has grown dramatically since the ‘reform and opening up’ policy in 1978 (Figure 1). According to the OIV, in 2014 China had the eighth largest global wine grape production and the largest global grape production. China has overtaken France as the country with the...
second largest vineyard area (table grape, wine grape and dried grape) after Spain. In 2015, China had the world’s second largest vineyard area (table grape, wine grape and dried grape) and the world’s eighth largest wine production (Table 1) (OIV, 2016). Even though the total vineyard area of China is now the second largest in the world, only 10% are for wine production (Decanterchina, 2016). Hence, further vineyard expansion for wine grape could be expected considering the huge market demand and the vast suitable territory of China.

IMPACT OF CLIMATE CHANGE ON WINE PRODUCTION

The sensitivity of wine production to changing climate factors will pose significant effects on yields and quality, ultimately impacting prices and revenues (Bardaji and Iraizoz, 2015). The decrease in suitable grape planting areas will adversely affect the quantity and quality of wine grapes produced (IPCC, 2014). Figure 2 illustrates the structural relationships between climate change and the wine production process. Vineyard location and climate variables have an immediate impact on grape quality and quantity. The effects of climate variables become apparent during the wine making and the wine storage period. Over the long term, vineyards could be relocated as owners seek more suitable climate conditions in order to maximize grape/wine quantity and quality.

Even though a multitude of individual climate factors have impacts on viticulture, temperature and water supply are the most important factors (Schultz and Jones, 2010).

Temperature plays a key role in viticulture. Each specific grape cultivar has its own range of optimal growing season temperatures, which determine the climate-maturity ripening potential (Table 2) (Jones, 2007). In North China, when the average annual minimum temperature is below -15 °C, it is necessary to adopt the soil-burying method to prevent Vitis vinifera from the damage of winter frost, and approximately 90% of the current vineyards in China need soil-burying (Wang S. et al., 2015). The Soil-Burying Line of China indicating areas with average annual minimum temperature...

![Figure 1. Primary wine-producing provinces and wine production of China. Source: China Sugar and Liquor Yearbook, 2011; Askci, 2015; National Bureau of Statistics of China, 2015.](image-url)
below -15 °C and requiring soil-burying in winter includes Shandong, Jiangsu, Henan, Shanxi, Shaanxi, Gansu, Sichuan, Yunnan and Tibet from east to west (Li H. et al., 2007b; Li H., Wang et al., 2007). Soil-burying could lead to increased labor intensity and production cost (Zhang J. et al., 2013).

Grapevine growth is initiated by a prolonged temperature above 10 °C in spring (Jones et al., 2005; Holland and Smit, 2014). The sum of mean daily temperature from 1st April to 31st October in the northern hemisphere is an indicator of heat available for wine grape growing defined as the Sum of Average Temperature over the same period (SAT) in viticulture (Jones and Davis, 2000; Szymanowski et al., 2007; Green and Szymanowski, 2012) (Table 2). Another indicator of heat available for viticulture is the Effective Accumulated Temperature (EAT) or the Growing Degree Days (GDD) which is the sum of the temperature value between mean daily temperature and 10 °C from 1st April to 31st October in the northern hemisphere (Amerine and Winkler, 1944; Li H., Li and Yang, 2009; Green and Szymanowski, 2012) (Table 2). Currently in China, accumulated temperatures are mainly used in viticulture climatic zoning studies (Li H. et al., 2007b).

Water availability is a limiting factor for the development of viticulture (De la Fuente et al., 2016). Vine grapes need a suitable amount of water during the growing period. In some cases, excessive rainfall can damage vine roots and grapes and cause floods, while in dry areas additional water supply may be provided by irrigation.

---

Table 1. World’s grape and wine. Source: OIV, 2016 and calculated by the authors.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Italy</td>
<td>50.0</td>
<td>Spain</td>
<td>1,021</td>
<td>France</td>
<td>6.04</td>
</tr>
<tr>
<td>2</td>
<td>France</td>
<td>47.4</td>
<td>China</td>
<td>830</td>
<td>Italy</td>
<td>5.87</td>
</tr>
<tr>
<td>3</td>
<td>Spain</td>
<td>37.3</td>
<td>France</td>
<td>786</td>
<td>Spain</td>
<td>5.19</td>
</tr>
<tr>
<td>4</td>
<td>USA</td>
<td>22.1</td>
<td>Italy</td>
<td>682</td>
<td>USA</td>
<td>3.20</td>
</tr>
<tr>
<td>5</td>
<td>Argentina</td>
<td>13.4</td>
<td>Turkey</td>
<td>497</td>
<td>Argentina</td>
<td>2.03</td>
</tr>
<tr>
<td>6</td>
<td>Chile</td>
<td>12.9</td>
<td>USA</td>
<td>419</td>
<td>Australia</td>
<td>1.56</td>
</tr>
<tr>
<td>7</td>
<td>Australia</td>
<td>11.9</td>
<td>Argentina</td>
<td>225</td>
<td>China</td>
<td>1.48</td>
</tr>
<tr>
<td>8</td>
<td>China</td>
<td>11.5</td>
<td>Iran</td>
<td>225</td>
<td>South Africa</td>
<td>1.46</td>
</tr>
<tr>
<td>9</td>
<td>South Africa</td>
<td>11.2</td>
<td>Portugal</td>
<td>217</td>
<td>Chile</td>
<td>1.37</td>
</tr>
<tr>
<td>Total</td>
<td>World</td>
<td>274.0</td>
<td>World</td>
<td>7,511</td>
<td>World</td>
<td>36.10</td>
</tr>
</tbody>
</table>

---

Figure 2. Climate change and the wine production process. Source: Own elaboration.
Spring frost will damage the grape buds and affect grape yield and quality; autumn frost will affect carbohydrate synthesis and reduce the cold tolerance ability of grapevine in winter (Li H., Wang et al., 2007). The choice of wine grape planting area is also related to the Frost-Free Period (FFP), which is usually defined as the number of consecutive days between the last day with a temperature below 0 °C in spring and the first day with a temperature below 0 °C in autumn (Wolf and Boyer, 2003; Li H. et al., 2007). The length of the FFP is often defined by the frost timing in the spring and fall and corresponds to approximately 160-200 days in the vast majority of the world’s viticulture regions (Wolf and Boyer, 2003; Jones, 2005). Sufficient FFP is needed in the processes of budburst, flowering, grape ripening, nutrient accumulation and grape frost resistance in winter (Wolf and Boyer, 2003; Li H. et al., 2007b; Holland and Smit, 2014) (Table 2).

In viticulture, we should also consider climate events such as extreme rainstorms, flood, drought, fog and hail which will affect grapevine production. Droughts and extreme rainstorms will have negative impacts on wine grape yield (Castex et al., 2015); hail in summer will damage the shoots, leaves and fruits and affect the yield and quality (Li H. et al., 2007a).

### TEMPERATURE AND ANNUAL ACCUMULATED TEMPERATURE

In the past century, China has experienced obvious impacts of global warming in annual mean temperature (10.1°C in 2014) (Figure 3). Data from 156 meteorological stations show that in 2010 the average temperature was 1.23°C higher than in 1950 (Li R.L. and Shu, 2013). The surface temperature in eastern China has increased by 1.52°C during 1909-2010 (Zhao P. et al., 2014). The temperature increase varied based on seasonal and geographical factors. The warming rate in winter was 0.04°C per year while it was 0.01°C per year in summer, and the north warmed more quickly than the south during 1960-2010 (Piao et al., 2010). According to data from 520 meteorological stations in China, during 1951-2005 both the accumulated temperature (≥10 °C, ≥0 °C) and its value increased (Miao et al., 2009). The annual effective accumulated temperature (≥10 °C), which is the sum of the temperature value between mean daily temperature and 10 °C for the whole year, generally has an increasing trend after 1985 (Liu S.H. et al., 2013). Since the 1990s, the whole Soil-Burying Line of China, which indicates areas with average annual minimum temperature below -15 °C and with the necessity to have vine soil-burying in winter, has advanced northward, leaving

### Table 2. Climate variables for viticulture.

(Source: Amerine and Winkler, 1944; Jones and Davis, 2000; Jones, 2005; Jones, 2007; Szymanowski et al., 2007; Li H., Li and Yang, 2009; Li H., Wang et al., 2009; Green and Szymanowski, 2012.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range of values</th>
<th>Class name or variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Growing Season Temperature (°C) in viticulture (Jones, 2007)</td>
<td>13-15</td>
<td>Cool temperature</td>
</tr>
<tr>
<td></td>
<td>15-17</td>
<td>Intermediate temperature</td>
</tr>
<tr>
<td></td>
<td>17-19</td>
<td>Warm temperature</td>
</tr>
<tr>
<td></td>
<td>19-24</td>
<td>Hot temperature</td>
</tr>
<tr>
<td>Sum of Active Temperature (SAT) from 1st April to 31st October in the northern hemisphere in viticulture (Jones and Davis, 2000; Szymanowski et al., 2007; Green and Szymanowski, 2012)</td>
<td>2000-2200</td>
<td>Very early ripening</td>
</tr>
<tr>
<td></td>
<td>2200-2500</td>
<td>Early ripening</td>
</tr>
<tr>
<td></td>
<td>2500-2700</td>
<td>Moderately early ripening</td>
</tr>
<tr>
<td></td>
<td>2700-2900</td>
<td>Late ripening</td>
</tr>
<tr>
<td>&gt;2900</td>
<td>Very late ripening</td>
<td></td>
</tr>
<tr>
<td>Effective Accumulated Temperature (EAT)/Growing Degree Days (GDD) from 1st April to 31st October in the northern hemisphere in viticulture (Amerine and Winkler, 1944; Li H., Li and Yang, 2009)</td>
<td>&lt;1371</td>
<td>Very early maturing grape varieties</td>
</tr>
<tr>
<td></td>
<td>1372-1649</td>
<td>Early maturing grape varieties</td>
</tr>
<tr>
<td></td>
<td>1649-1927</td>
<td>Late maturing grape varieties</td>
</tr>
<tr>
<td></td>
<td>1927-2204</td>
<td>Acid grape varieties</td>
</tr>
<tr>
<td>&gt;2205</td>
<td>Very acid grape varieties</td>
<td></td>
</tr>
<tr>
<td>Frost-Free Period (FFP) (days) in viticulture (Jones, 2005; Li H., Wang et al., 2009)</td>
<td>&lt;160</td>
<td>Unsuitable region</td>
</tr>
<tr>
<td></td>
<td>160-220</td>
<td>Suitable region</td>
</tr>
<tr>
<td>&gt;220</td>
<td>Suitable region but wine quality affected</td>
<td></td>
</tr>
</tbody>
</table>
vast areas (including some part of Xinjiang) suitable for viticulture without the necessity to have vine burying in winter (Li H., Wang et al., 2007).

From the literature review (Table 3), we can observe a trend of increasing temperature in eight wine-producing provinces (Ningxia, Xinjiang, Shandong, Tianjin, Jilin, Gansu, Hebei, Shaanxi) and an increasing number of days with specific annual active accumulated temperature (≥6 °C, ≥5°C, ≥10 °C) in seven wine-producing provinces (Ningxia, Xinjiang, Shaanxi, Heilongjiang, Gansu, Hebei, Tianjin) over a long period (more than 40 years). Although the literature review does not cover all of the wine-producing provinces, we can see the correlation with the national trend of increasing annual mean

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Period</th>
<th>Region</th>
<th>Tendency</th>
<th>References</th>
<th>Possible benefits</th>
<th>Possible harms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1961-2004</td>
<td>Ningxia</td>
<td>Annual mean temperature</td>
<td>Chen S.G., et al., 2008a</td>
<td>Current cold areas may be suitable to grow grapes that can only grow in warm areas (Mozell and Thach, 2013).</td>
<td>The quality and yield of grape may be influenced (Fraga et al., 2012; Nicholas and Durham, 2012).</td>
</tr>
<tr>
<td></td>
<td>1960-2009</td>
<td>Frequency of extreme heat days</td>
<td>Zhang M.J., et al., 2012</td>
<td>The opening process accelerates (Holland and Smit, 2010).</td>
<td>The sugar content increases for some grape varieties in some regions (Mozell and Thach, 2014).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2010</td>
<td>Tianjin</td>
<td>Degree of extreme cold days</td>
<td>Pu et al., 2014</td>
<td>Less frost events (Jones, 2007).</td>
<td>The acidity of grape decreases for some grape varieties in some regions (Mozell and Thach, 2014).</td>
</tr>
<tr>
<td></td>
<td>1961-2003</td>
<td>Gansu</td>
<td>Mean temperature of January</td>
<td>Zhang S.P., et al., 2011</td>
<td>The sugar content increases for some grape varieties in some regions (Mozell and Thach, 2014).</td>
<td>The alcohol content increases for some grape varieties in some regions (Mozell and Thach, 2014).</td>
</tr>
<tr>
<td></td>
<td>1961-2010</td>
<td>Hebei</td>
<td>Annual mean temperature</td>
<td>Liu S.M., et al., 2009</td>
<td>The acidity of grape decreases for some grape varieties in some regions (Mozell and Thach, 2014).</td>
<td>Higher risk of pests and diseases (De Ondoia, 2010).</td>
</tr>
<tr>
<td></td>
<td>1961-2001</td>
<td>Xinjiang</td>
<td>Annual mean temperature increased 0.29 °C per decade</td>
<td>Shen et al., 2014</td>
<td>The alcohol content increases for some grape varieties in some regions (Mozell and Thach, 2014).</td>
<td>Impede photosynthesis and hence respiration process (Ashkenafier and Storchmann, 2016).</td>
</tr>
<tr>
<td></td>
<td>1961-2013</td>
<td>Shaanxi</td>
<td>Mean temperature of each season</td>
<td>Wang Y.H., et al., 2014</td>
<td>The quality and yield of grape may be influenced (Jones, 2007; Holland and Smit, 2014).</td>
<td>Fruit burn (De Ondoia, 2010; Hairdota et al., 2010).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Period</th>
<th>Region</th>
<th>Tendency</th>
<th>References</th>
<th>Possible benefits</th>
<th>Possible harms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Active Accumulated Temperature</td>
<td>1961-2003</td>
<td>Ningxia</td>
<td>Annual number of days (≥6 °C, ≥10 °C)</td>
<td>Zhang Z. and Lin, 2008</td>
<td>Longer favorable growth period (Holland and Smit, 2014).</td>
<td>The quality of grape may be influenced (Jones, 2007; Holland and Smit, 2014).</td>
</tr>
<tr>
<td></td>
<td>1961-2010</td>
<td>Xinjiang</td>
<td>Annual number of days (≥8 °C)</td>
<td>Pu et al., 2013</td>
<td>More areas may be suitable for grape planting (Li H., et al., 2007b; Li H., et al., 2007a).</td>
<td>Grape yield may be decreased by excess heat (Jones, 2007).</td>
</tr>
<tr>
<td></td>
<td>1961-2003</td>
<td>Gansu</td>
<td>Annual Active Accumulated Temperature (≥6 °C, ≥10 °C)</td>
<td>Li S.X., et al., 2005</td>
<td>The quality of grape may be influenced (Jones, 2007; Holland and Smit, 2014).</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Annual mean temperature of China. Source: China Meteorological Administration, 2015.
temperature (Figure 3). These changes may have caused possible benefits such as an increase in the number of areas suitable for wine grape planting and possible harms such as a reduction in grape and wine quality (Table 3).

**PRECIPITATION AND WATER SCARCITY**

The precipitation trends have shown distinctive regional and seasonal variations, but there has been a general decreasing trend throughout the entire country. From 1960 to 2010, three periods of precipitation transitions occurred in the 1970s, 1980s and 1990s, and the increase and decrease of precipitation moved along with the latitude (Zhao H.R., 2013; Wang Y.J. and Yan, 2014). While southern China has experienced an increasing trend of rainfall in summer and winter, northeastern China has experienced a significant decrease of precipitation in summer and winter (Piao et al., 2010; Li R.L. and Shu, 2013).

Approximately 98% of the surface water in China is recharged by precipitation (Jiang, 2009). From precipitation data of the primary wine regions in 2010 (Figure 4), we can see that the majority of regions have lower precipitation amounts than the national level. In Ningxia, Gansu and Xinjiang, the annual mean precipitation is considerably less than the national level. Changes in precipitation have been observed over long periods (more than 40 years) in six wine-producing provinces (Ningxia, Tianjin, Shandong, Gansu, Shaanxi, Hebei) with decreasing annual amount of precipitation or decreasing annual precipitation days (Table 4). These changes may have positive impacts, such as fewer pests and diseases. However, the changes may also have negative impacts, such as increased drought frequency and increased irrigation cost (Table 4).

In 2013, China ranked 102nd of 176 nations and regions with 2083 cubic meter water resource per capita (World Bank, 2015). This ranking was lower than in many wine-producing countries (Figure 4). With the exception of Heilongjiang, Jilin, Xinjiang and Yunnan, the available water per capita in the other main wine-producing regions is lower than the national average. Xinjiang has vast amounts of water stored in glaciers. Yunnan has an uneven distribution of precipitation, and irrigation is difficult due to the

![Figure 4. Annual mean precipitations and per capita water resource of China. Source: National Bureau of Statistics of China, 2015; World Bank, 2015.](image-url)
obstruction of high mountains, all of which lead to water scarcity.

**FROST-FREE PERIOD**

Chinese studies indicate that between 1964 and 2003, in China, the acreage with a FFP above 160 increased significantly, especially between 1984 and 2003, while the First Frost Day (FFD) was delayed and the Last Frost Day (LFD) was advanced (Li H., Wang et al., 2007; Li H., Wang et al., 2009). The Yongning County, which is bordered by the Yellow River to the west and the Helan Mountain to the east, is one of the main wine-producing regions of Ningxia. Meteorological observations between 1952 and 2013 in Yongning County indicate that the FFP had an increasing trend (164 days in 1952 and 189 days in 2013) and the FFD was delayed (26th Sep in 1952 and 16th Oct in 2013) (Figure 5).

In eight wine-producing provinces (Shandong, Ningxia, Shaanxi, Xinjiang, Liaoning, Jilin, Heilongjiang, Tianjin), studies had indicated the increasing trend of FFP over 50 years, delayed FFD, and advanced LFD (Table 5). This finding may provide an opportunity for cultivation of more grape varieties and lead to more areas suitable for viticulture. However, grape quality and grape yield may be affected (Hadarits et al., 2010; Fraga et al., 2012) (Table 5).

**EXTREME CLIMATE EVENTS**

With the changing climate, there has been an increasing trend in periods of remarkable drought and flood, leading to challenges to agriculture and the Chinese wine industry. The most significant droughts appeared in 1978 and 2000, strongly affecting the crop production in China. Figure 6 indicates total agricultural crop area covered (crop yield loss >10%) and affected (crop yield loss >30%) by drought and flood in China from 1950 to 2014. In the 1990s and 2000s, strong floods caused by heavy rains impacted the entire country. In 1991, 1998, 2003, and 2010, serious floods hit China, leaving vast crop areas affected by flood (Figure 6).

Regionally, increased incidence of extreme rainstorms in Ningxia, Hebei and Xinjiang over a long period may have alleviated the drought problem but may have also increased the risk of flood damage and vineyard destruction (Table 6). Due to the increased severity of drought conditions in five wine-producing provinces (Ningxia, Liaoning, Shaanxi,
Henan, Yunnan), an increased investment in irrigation infrastructure may be required.

In Ningxia, Xinjiang, Shaanxi and Yunnan, changes in the density and frequency of fog over more than 40 years may have impacted the growth process of grapes. In Ningxia, Tianjin, Hebei and Yunnan, the decreasing frequency of hail may have reduced the damage to vineyards.

**CLIMATE CHANGE ADAPTATION STRATEGIES FOR THE CHINESE WINE INDUSTRY**

Adaptation strategies can reduce the impacts of climate change and are a major challenge for viticulturists for the coming decades (Van Leeuwen et al., 2007; Iglesias et al., 2012; Ren et al., 2013; Ollat and Touzard, 2014b). Climate change adaptation can be planned at the regional, national, and international level. We provide recommendations to the wine industry for adaptation strategies based on current Chinese climate change policies and studies of wine and adaptation (Figure 7).

1. **Policy strategies**

In recent years, there have been changes in Chinese government policy to support agriculture in adapting to climate change. China has promulgated a series of laws to promote agricultural development addressing the importance of sustainable water use (China’s...

There have also been efforts to address climate change adaption at the regional level, particularly in the Ningxia Province. The climate change situation and challenges in Ningxia have been analyzed and an adaptation and mitigation plan highlighting the urgency to take actions has been proposed (Scheme of Adaptation for Climate Change in Ningxia, 2009). The first wine regional protection regulation of China was approved in Ningxia in 2012 and was intended to ensure an environmental protection for the grape growing/wine-producing regions (Regulation on the protection of Eastern Foot of Helan Mountain Wine Region in Ningxia Hui Autonomous Region, 2012).

However, climate change adaptation legislation targeting the wine industry should be further established and implemented at the national and regional level (China’s National Climate Change Programme, 2007).

2. Financial strategies

The Chinese government has invested over 20 billion Yuan in disaster prevention and mitigation capabilities and 1 billion Yuan in dry land water-saving agriculture (China’s Policies and Actions on Climate Change, 2014). During the period from 2001 to 2005, the government invested more than 2.5 billion Yuan for climate change-related scientific and technological work (China’s Policies and Actions for Addressing Climate Change, 2008). The investments increased to 7 billion Yuan during 2006-2010, and there have been continued increases since. Adequate financial support such as facility investment, agricultural insurance and subsidy for both industrial development and climate change adaptation will be essential for continued growth and development of the grape planting and wine-producing regions of China.
3. Technical strategies

Water resources are essential for viticulture. Chinese policy has provided several technological measures to enhance the efficiency of water consumption in agriculture (China Water Conservation Technology Policy Outline, 2005). Low carbon agriculture should be promoted and agricultural waste should be recycled for sustainable agriculture. Additionally, additional irrigation facilities should be built and existing facilities should be improved in order to conserve water. It is also proposed that when crops and farming systems are chosen, climate change should be taken into consideration. The need to develop high-quality stress resistant crop varieties is also addressed (China’s National Plan on Climate Change 2014-2020, 2014). Furthermore, management practices of pests and diseases should be adapted to new strains or new pathogens (Goulet, 2014).

Climate-based zoning has been attempted for viticulture in order to guide grape planting and wine production. In Xinjiang and Ningxia, the viticulture climatic zoning classification system uses three indexes: FFP, dryness index (from April to September) and mean lowest temperature below -15 °C (Wolf and Boyer, 2003; Tonietto and Carbonneau, 2004; Wang H. et al., 2010; Li H., Wang and Wang, 2011). In the Shaanxi and Jingjintang area, which includes Beijing, Tianjin and some areas of Hebei, the amount of precipitation from July to September is used as an index (Li H. et al., 2012). Additional criteria have been proposed for viticulture in Hebei (Battaglini et al., 2009, 2012).

<table>
<thead>
<tr>
<th>Climate Event</th>
<th>Period</th>
<th>Region</th>
<th>Tendency</th>
<th>References</th>
<th>Possible Benefits</th>
<th>Possible Harms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme Rainstorm</td>
<td>1961-2005</td>
<td>Ningxia</td>
<td>Annual days of extreme rainstorm ↑</td>
<td>Chen X.G. et al., 2008b; Li X. et al., 2013</td>
<td>Alleviated drought problem (Battaglini et al., 2009; Fraga et al., 2012).</td>
<td>Greater frequency of flood damage and loss of soil nutrient (Fraga et al., 2012).</td>
</tr>
<tr>
<td></td>
<td>1961-2010</td>
<td>Hebei</td>
<td>Intensity and amount ↑</td>
<td>Gao et al., 2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2005</td>
<td>Xinjiang</td>
<td>Annual frequency of rainstorm ↑</td>
<td>Sun et al., 2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought</td>
<td>1951-2000</td>
<td>Ningxia</td>
<td>Frequency of drought ↑</td>
<td>Liang et al., 2007</td>
<td>The grape-growing conditions over humid areas may be improved (Battaglini et al., 2009; Fraga et al., 2012).</td>
<td>Higher cost of irrigation and facilities (Battaglini et al., 2009; Fraga et al., 2012).</td>
</tr>
<tr>
<td></td>
<td>1961-2004</td>
<td>Hebei</td>
<td>Especially in winter frequency of drought ↑</td>
<td>Sing et al., 2007</td>
<td></td>
<td>Decreased grape yield (Hadarit et al., 2010; Ollat et al., 2016).</td>
</tr>
<tr>
<td></td>
<td>1978-2010</td>
<td>Hebei</td>
<td>Degree of drought ↑</td>
<td>Tan et al., 2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1988-2007</td>
<td>Liaoning</td>
<td>Geographical distribution of drought ↑</td>
<td>Zhao X.L. et al., 2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2010</td>
<td>Shaanxi</td>
<td>Degree of drought ↑</td>
<td>Cai et al., 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2008</td>
<td>Henan</td>
<td>Degree of drought ↑</td>
<td>Zhang H.W. et al., 2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2011</td>
<td>Yunnan</td>
<td>Degree and time duration of drought ↑</td>
<td>Zhang W.C. et al., 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1960-2010</td>
<td>Shaanxi</td>
<td>Annual frequency after 2000↑</td>
<td>Zhang H.F. et al., 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2008</td>
<td>Yunnan</td>
<td>Annual frequency↑</td>
<td>Tao et al., 2011b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hail</td>
<td>1961-2004</td>
<td>Ningxia</td>
<td>Annual frequency of hail ↓</td>
<td>Wu et al., 2008; Yang et al., 2012</td>
<td>Lower frequency of hail damage (Fraga et al., 2012).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1961-2010</td>
<td>Hebei</td>
<td>Annual frequency of hail ↓</td>
<td>Min et al., 2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1979-2008</td>
<td>Tianjin</td>
<td>Annual frequency of hail ↓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1979-2008</td>
<td>Hebei</td>
<td>Annual and seasonal frequency↓</td>
<td>Tao et al., 2011a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Provincial extreme climate events and effects on viticulture.
including China. Combining grape zoning methodology with climate change simulations such as climate change scenarios can enhance viticulture adaptation for the future. To deal with the uncertainties of future climatic simulations in climate change impact studies, different climatic scenarios and downscaling methods should be considered (Caubel et al., 2014). Integrated models such as ecophysiological model and the MILA-STICS model can predict complex impacts for climate change (Caubel et al., 2014; Piéri and Lebon, 2014). Multi-scale climatic approaches such as the ANR-TERVICLIM and GICC-TERADCLIM research programmes, which intend to observe and simulate climate and climate change at local scale, can produce a scale assessment of climate change impacts in different wine-producing regions worldwide (Quénol and Bonnardot, 2014).

Mozell and Thach (2014) have provided vineyards and wineries with a series of practical solutions for adapting to climate change. Fifteen solutions for vineyards are provided to offset rising temperatures, water shortages, increases in heat, drought and light intensity and their impacts such as earlier maturation, and increases in the number of pests. Eleven solutions are provided to enhance wine production in order to offset warmer temperatures, increases in sugar and alcohol levels, reduction in acidity, vintage variability, and earlier harvest and ripening.

Further research is needed to assist the Chinese wine industry in adapting to climate change. An interdisciplinary approach will be needed that incorporates improvements in grape resistance, new grape planting and wine making technology, disaster response, climate change adaptation management and social and economic evaluation.

4. Institutional strategies

Institutional changes are indispensable for effective adaptation solutions (Ollat and Touzard, 2014a; Ollat and Touzard, 2014b). The Chinese government has strongly promoted an awareness and understanding of climate change impact in general, but a stronger focus is needed on how climate change impacts the wine industry in particular. The broadcast of climate change knowledge and adaptation for wine producers and wine traders can be promoted by media, materials, forums, campaigns and training during which regional wine associations in China can participate. Wine institutes in universities can assume the responsibility for educating the public. Electronic platforms can be established to broadcast and share information.

5. Collaborative strategies

Climate change demands the attention of the global wine industry. The World Conference on Climate
Change and Wine has been organized three times by the Wine Academy of Spain to address the need for climate change adaptation in viticulture (Li Y.B., 2015). Several investigations of climate change and viticulture are underway in France and other wine-producing countries (Ollat and Touzard, 2014b; Yzarra et al., 2015). In France, the multidisciplinary LACCAVE project (long-term adaptation to climate change in viticulture and enology) involving 23 different laboratories from the National Institute for Agricultural Research of France (INRA), the National Center for Scientific Research (CNRS) and several French universities aims to analyze the impacts of climate change on viticulture and wine and to assess current and design future adaptation strategies (Ollat et al., 2016). With a goal to establish a scientific framework addressing climate change issues in viticulture, this project is organized in seven areas: characterization and perception of climate change; physiological and genetic bases of grapevine adaptation to climate change; development of technical innovations for adaptation to climate change; evaluation of the impact of technical innovation at a territorial scale; analysis of the evolution of economic strategies; data management and analysis; and elaboration of strategic scenarios for 2050 (Ollat and Touzard, 2014b). The importance of communication and cooperation with developed countries and international organizations has been highlighted (China’s Policies and Actions for Addressing Climate Change, 2015). As China moves from the insular policies of the past to increased communication and sharing of technology at the international level, the Chinese wine industry will greatly benefit.

CONCLUSIONS
In the last several years, domestic wine production has experienced a dramatic increase in China, boosted by rising consumption and a favorable economic situation. This increase faces important future challenges, a number of them emerging from the impacts of climate change, which may affect the quantity and quality of the wine production and even the vineyard location.

The analysis of the climate trend in China, which is focused on variables with climate relevance to viticulture, exhibits inconsistent effects, and confirms the relevance of the changes in the primary wine-producing regions.

The literature suggests a general tendency of increasing temperatures and accumulated temperature, water scarcity with higher frequency of extreme events and increasing number of frost-free days, all of which will bring both challenges and opportunities to the young Chinese wine industry.

The identified effects indicate the need for more research at the regional level for an accurate assessment of climate change impact on the Chinese wine industry and a proper design of adaptation measures, considering the specific needs and characteristics of wine production. These specific adaptation measures have to be implemented under the national framework of climate change adaptation and need to consider the coordination of policy, financial, technical, institutional and collaborative strategies.

Acknowledgments: The authors would like to acknowledge the financial support from the China Scholarship Council (CSC) and the research support from the Research Center for the Management of Agricultural and Environmental Risks (CEIGRAM) of the Universidad Politécnica de Madrid (UPM).

REFERENCES


Li H., Li J.G. and Yang H.C., 2009. Review of grape and wine industry development in recent 30 years of


Ollat N., Touzard J.M. and Van Leeuwen C., 2016. Climate change impacts and adaptations: new challenges for the wine industry. *J. Wine Econ.* 11, 139-149.


Tao Y., Duan X., Duan C.C. and Duan W., 2011b. The change characteristics of fog in Yunnan during the nearly 50 years. *J. Yunnan Univ.* 33, 308-316 (in Chinese).


