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2016

Identifying key factors influencing sustainable wine production

A case study on the wine sector in the Porto and Douro region, Portugal

Master Thesis – Sustainable Business and Innovation

Title	Identifying key factors influencing sustainable wine production - A case study on the wine sector in the Porto and Douro region, Portugal
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Number of words	28.538
Date	09-12-2016

I think this is the way, sustainability is not something that you buy, it's not something that you can have easily. Sustainability is a strategical move.

IV 3 - Sogrape Vinhos S.A.

Acknowledgements

It was the 29th of November, 2015, when the first contact was established between me, at that moment in Slovenia, and Bento Amaral, in Porto, Portugal. Thanks to that e-mail response, the project eventually evolved into this thesis. Therefore I would like to thank Bento Amaral for hosting me and my research at the IVDP for those 6 months, and Ana Faria for being my supervisor at the IVDP and helping me get in touch with interviewees. My stay at the IVDP would not have been the same without my two friends, Barbara Amaral and Isabel Valle, thank you for all your support and port wine lectures (and tastings). The stay in Porto would not have been the same if me and my girlfriend weren't so openly welcomed by our great friends Mario and Juliana, whom we met through Climate-KIC.

During the last year this master thesis went through various phases, and thanks to the help of many great people it has come to a conclusion. A special thanks to dr. Walter Vermeulen for providing me with necessary directions in an explorative interview during the research proposal phase. I would like to thank all interviewees for their essential contribution to this thesis. It was inspiring and a pleasure talking to all of you. I would like to thank my friend Joe for helping me by proofreading the thesis. But I am most indebted to my supervisor prof. dr. Ellen Moors and her thoughtful, patient and thorough support whilst writing my research proposal and my thesis. Your support has been invaluable, thank you so much.

My gratitude goes to my girlfriend, Manca, for inspiring me to look for thesis possibilities abroad, and for supporting me through my entire thesis period. Last but not least, I would like to give a special thanks to my mother, Mirjam, your support has been invaluable.

Abstract

The agricultural sector is an important contributor to the unsustainable use of natural resources today and poses large sustainability challenges in the future. This is due to a growing world population that consumes an ever increasing resource intensive diet. The wine sector, while commonly viewed as a natural and low-impact sector, has significant environmental impacts, such as water use, loss of biodiversity and greenhouse gas emissions. Hence, it becomes increasingly important to incorporate sustainable wine production in the worlds wine regions. New World wine regions (e.g. California, New Zealand) have shown to rapidly develop their sustainable wine production, unlike Old World wine regions (e.g. European regions like France, Spain, Portugal).

The purpose of this study is to find factors that influence sustainable wine production. Therefore, both the Regional Innovation System (RIS) and the Sectoral System of Innovation (SSI) are integrated into a Regional and Sectoral Innovation System (RSIS). From this approach, influencing factors are explored and determined whether they are supporting or hindering sustainable wine production. The Sustainability Assessment of Farming and the Environment (SAFE) framework is used to identify sustainability challenges in the case-study region and to identify the sustainability element of factors influencing sustainable wine production. As a case-study region, the Old World Porto and Douro wine region in Portugal is chosen. Next to the Old World case-study region, a general comparison with the New World wine region California is executed, to find discrepancies between the two. The main sustainability challenges identified in the Porto and Douro wine region are; excessive pesticide use, genetic erosion, water scarcity, the low price of wine, and decreasing population in the viticultural area. The main hindering factors to sustainable wine production identified are related to the legislative framework, the financial risks involved, and the resistance to change mind-set of people working in the wine sector. The main supporting factors to sustainable wine production identified are related to a growing market for sustainable wines, increase in wine tourism and entrepreneurship. Due to the comparison with the New World wine region, the inadequate representation of the farmers has been identified as a hindering factor to sustainable wine production in the Porto and Douro wine region. It is recommended that the Porto and Douro wine region governing organizations explore the possibility to introduce mechanisms that support, reward, and educate on, sustainable wine practices, considering the supporting and hindering RSIS factors that are identified.

Terminology and abbreviations

ADVID	*Associação para o Desenvolvimento da Viticultura Duriense.*
AEVP	*Associação das Empresas de Vinho do Porto.*
AJAP	*Associação de Jovens Agricultores de Portugal.*
CAWG	*California Association of Winegrape Growers*
CEEV	*Comité Européen des Entreprinses Vins.*
Cover crop	*Vegetation between the rows of vine on the vineyard.*
CSWA	*California Sustainable Winegrowing Alliance*
DDT	*Dichlorodiphenyltrichloroethane.*
Douro	*The region that starts 90km east of Porto that includes the Douro Demarcated Region (DDR). The main river is called Rio Douro, meaning 'river of gold'.*
Grey water	*Water that has been used to for treatment such as cleaning machinery that was used for winemaking.*
INEGI	*Institute of Science and Innovation in Mechanica land Industrial Engineering.*
INIAV	*Instituto Nacional de Investigação Agrária e Veterinária.*
IOBC	*The International Organisation for Biological and Integrated Control.*
IPM	*Integrated Pest Management*
IV	*Interviewee.*
IVDP	*The wine institute for the Douro and Port wines. Instituto dos Vinhos do Douro e Porto.*
IVV	*Instituto da Vinha e do Vinho.*
LCA	*Life Cycle Assessment.*
OIV	*The international Organisation of Vine and Wine.*
Pesticide	*The use of substances with the purpose of destroying or limiting pests on the vineyard. They can be used against fungi (fungicides), plants (herbicides), insects (insecticides), bacteria (bactericides) and many in-between forms (IV 13).*
PM	*Particulate matter, a characteristic of air quality.*
Port wine (port)	*Fermented grape juice with added brandy and an alcohol percentage of around 20%.*
Porto	*The city on the coast of the Atlantic Ocean. It is sometimes called 'Oporto', coming from the Portuguese meaning 'the Porto', or 'the harbour'.*
PORVID	*Associação Portuguesa para a Diversidade da Videira.*
Quinta	*The usual translation is "wine estate". In Portuguese, Quinta means, above all, the vineyards; a Douro quinta is more than a country property with a vineyard on it. Some quintas have no buildings on them at all.* (Paulo Martins, 2011).
RIS	*Regional Innovation System*
RSIS	*Regional and Sectoral Innovation System*
SAFE	*Sustainability Assessment of Farming and the Environment*
SAW	*Sustainable Australia Winegrowing*
SCOF	*Standing Committee on Organic Farming.*
Shipper	*A synonym for the word merchant used by winemakers.*
SSI	*Sectoral System of Innovation*
Still wine	*The same as 'wine', it is a term used to distinguish between wine and port wine.*
SWNZ	*Sustainable Winegrowing New Zealand*

SWSA	*Sustainable Wine South Africa*
Vine	*A grape plant that produces grapes suitable for wine production*
Viticulture	*Cultivating vine for the production of wines.*
WASP	*Wines of Alentejo Sustainability Pogramme*
Wine	*Fermented grape juice with an alcohol percentage up to 14%.*

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1. Introduction

The global consumption of natural resources and land use change for economic growth is a continuing threat to the earths' climate and biodiversity (IPCC, 2014). To change this, it is vital to not only transform the energy sector, but also the non-energy sectors (Krabbe *et al*., 2015; International Energy Agency, 2016). While the energy and heat production sector accounts for 25% of all human induced greenhouse gas emissions (Smith *et al*., 2014), the agriculture, forestry and other land use sector accounts for an almost equal amount, at 24% (IPCC, 2014). Additionally, the world population is expected to grow over nine billion people by 2050 (UN, 2015). This population consumes an increasingly resource-intensive diet (Garnett *et al*., 2013; OECD, 2013). In order to feed this growing population, the agricultural sector is projected to produce 70-100% more products by 2050 (Tomlinson, 2013). This causes increased competition for land, water and energy (Garnett *et al*., 2013), which makes the agricultural sector a very important contributor to the unsustainable use of natural resources today and it poses large sustainability challenges in the future (Charles *et al.*, 2010; Sands *et al*., 2014).

The awareness of the need for a more sustainable use of land, material, water and energy resources in the agricultural sector is increasing since the scientific community, policy makers, regulation and firms increasingly address the current sustainability issues (Markard *et al*., 2012). The wine sector is an example of an agricultural sector that is dealing with sustainable development challenges (Alonso & Liu, 2012; Cusmano *et al*., 2010; Dodds *et al*., 2013; Flint & Golicic, 2009; Hall & Mitchell, 2000; Ras & Vermeulen, 2009; Santini *et al*., 2013). While commonly viewed as a natural and low-impact sector, this sector has not been scrutinized on environmental impacts like other industries (Christ & Burritt, 2013). However, the wine sector has significant environmental impacts, such as water use through irrigation, loss of biodiversity through land, pesticide and fertilizer use, water pollution through the use of fertilizers and pesticides, waste production, and greenhouse gas emissions (Christ & Burritt, 2013). Depending on the region, social sustainability issues are also a concern, such as poverty and a lower degree of education of farmers (Santini *et al*., 2013).

The challenge to transform the global wine sector to a more sustainable sector lies in the many geographically distributed wine regions. Until the 1980s the 'Old World' wine regions dominated the international wine market (Cusmano *et al*., 2010). These are the wine regions, mostly European, that produced wine for over 2000 years, in countries like France, Italy, Spain, and Portugal (Banks & Overton, 2010; Campbell & Guibert, 2006; Fraga *et al*., 2012; UNESCO, 2016). The 'New World' wine regions started challenging these market leaders since the 1990s (Cusmano *et al*., 2010), in countries such as Australia, New Zealand, USA and South Africa (Campbell & Guibert, 2006). Although relatively new to the wine sector, these rapidly growing New World wine regions have been responsive to new scientific approaches and changes in wine consumption habits (Cusmano *et al*., 2010). Consequently, the implementation of sustainability programs is mostly observed in New World wine regions (Castka & Corbett, 2014; Initiative *et al*., 2010).

It is important to change to a more sustainable wine sector in the Old World, because 38% of all viticultural area is located in Europe (Old World) in 2011, as can be seen in figure 1 (Fraga *et al*., 2012). These European regions have been noted to be lacking sustainability programmes, indicating a lower degree of sustainable wine production (Aylward, 2003; Szonolki, 2013).

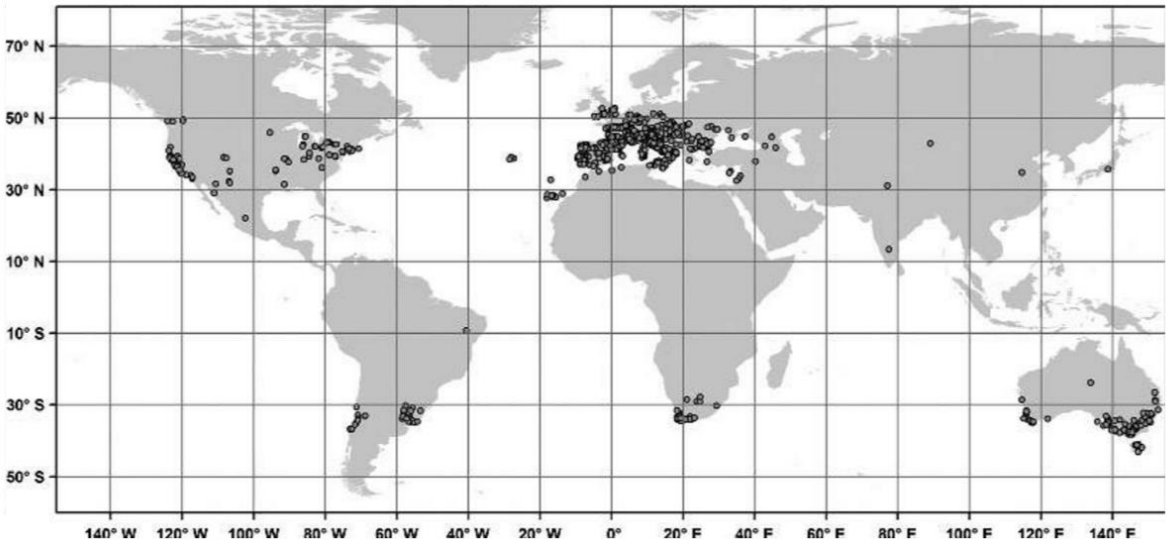

Figure 1. The geographical distribution of the global wine regions, as pictured in Fraga et al*.,* (2012). *Each dot represents a viticultural region.*

As a measure by the EU, additional financial resources are allocated to stimulate the public-private regional knowledge transfer to enhance the innovative capabilities of the wine regions (Gerstlberger, 2004). The knowledge transfer and innovative capabilities are key aspects of innovation systems[1] (Hajek *et al*., 2014; Klerkx *et al*., 2012; Potts, 2010). The promotion of these innovation systems is considered an opportunity for economic, technological, ecological and social renewal; thus stimulating a sustainability transition (Gerstlberger, 2004; Markard *et al*., 2012). A sustainability transition is the *''fundamental transformation towards more sustainable modes of production and consumption''* (Markard *et al*., 2012, pp. 955). In short, the EU has a specific interest in well-functioning regional wine innovation systems to increase the level of sustainable wine production in its regions.[2]

In order to study these innovation systems and their role in a sustainability transition of the wine sector, both a Regional Innovation System (RIS) (Cooke, 1997) and a Sectoral System of Innovation (SSI) (Cusmano *et al*., 2010) are used. A RIS is a group of actors such as producers, consumers, institutions, researchers, entrepreneurs and investors that engage in formal and informal long-term cooperation and knowledge sharing at a regional level to realize competitive advantage through innovations (Coenen *et al*., 2012; Cooke, 1997; Hajek *et al*., 2014). By making the RIS sector specific, globalization of production networks and knowledge flows are taken into account as well (Cusmano *et al*., 2010). This is not the case when only considering the region as a functional area, but it becomes apparent when also considering the sector as a functional area. This sectoral approach is the SSI (Cusmano *et al*., 2010). The globalization of production networks and knowledge flows is an important aspect of the SSI, as sustainable production methods can come from abroad (Neto *et al*., 2013). Because the wine industry is a global industry, with many separated wine regions in both the 'Old World' and the 'New World', this regional approach is essential to understand the innovation system in the wine sector. Therefore, this research focuses on the implementation of sustainable wine production, using both a Regional and Sectoral Innovation Systems (RSIS) perspective.

[1] An innovation system is defined as ''*The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies''* (Freeman, 1987; OECD, 1997 pp. 11)

[2] A few examples of sustainable wine production methods are the use of cover crops to protect the soil from erosion, owl boxes that provide haven for owls as a natural rodent pest control, the use of soil probes to monitor soil moisture to conserve water (Beckstoffer vineyards, 2016).

The aim of this study is to obtain a better understanding of how the RSIS is supporting or hindering the transition to sustainable wine production in an Old World wine region. In order to study this, an exploratory case study is executed at the Porto and Douro wine region in Portugal. This region is an example of an Old World wine region where both environmental and social sustainability issues exist (Jones & Alves, 2011; Neto *et al.*, 2013; Personal communication IVDP, 2016). To gain deeper insights in wine sustainability transitions[3], RSIS characteristics of the Old Wine region will be compared to RSIS characteristics of a New World region as possible lessons can be learned from the New World wine region (Cusmano *et al*., 2010; Dodds *et al*., 2013; Jacobsson & Bergek, 2011). Additionally, case study specific recommendations are devised that could speed up the sustainability transition of the Old World wine regions. Therefore, the following research question will be addressed in this research:

How do the regional and sectoral characteristics of the wine innovation system in the Porto and Douro region in Portugal support or hinder sustainable wine production of the (regional) wine sector and which strategies can be devised to improve the sustainability performance of the Porto and Douro wine region?

In order to determine the characteristics of sustainable wine production from these RSIS, the *Sustainability Assessment of Farming and the Environment* (SAFE) framework by Van Cauwenbergh *et al*., (2007) was used. This hierarchical framework presents a tool for assessing the sustainability of agricultural systems on small and large scales (Van Cauwenbergh *et al*., 2007), and the extensive indicator list (appendix 3) provides a solid foundation to assess the sustainability performance of agricultural production methods.

1.1 Scientific relevance

A comparison between the characteristics of the RIS and the SSI has been made before (Cooke, 2002), but using these two approaches to find the hurdles to implement sustainable wine production is rather new. Insight can be gained on the applicability of the RSIS approach to identify supporting and hindering factors to sustainable production. Reasonably novel is the general comparison between the Old World versus the New Worlds wine innovation system characteristics. This comparison can provide valuable insights on how sustainability transitions are hindered or supported by the RSIS. Lastly the applicability of the SAFE framework to filter for sustainability related influencing factors is tested in this study.

1.2 Social relevance

The findings of this study lead to hurdles that limit the sustainability transition of the Porto and Douro wine region. These findings can directly contribute to a change in the regional wine innovation system that would drive sustainable wine production in this region. Many sectors in the agricultural world are regionally bound but are also depended on global production networks and knowledge flows. Thus, findings of this study can contribute to a reduced sustainability impact of the agricultural sector worldwide. It could, therefore, lead to limit the agricultural share in climate change and decrease the social challenges in the agricultural regions.

[3] A sustainability transition is defined as the ‘’*fundamental transformation towards more sustainable modes of production and consumption’’* (Markard *et al*., 2012, pp. 955).

1.3 Outline

This thesis is organised as follows: Chapter 2 explains the theories and concepts used to give a preliminary answer to the research question. A conceptual framework is presented. Chapter 3 gives the methods used: the research design, including the case study selection, data collection, data analysis and the validity and reliability of the research method. Chapter 4 gives the case description, including the history and the supply chain of the Porto and Douro region. Chapter 5 presents the results and the main sustainability challenges that were identified in the Porto and Douro region. In chapter 6 the RSIS is elaborated of the Porto and Douro wine region. Chapter 7 analyses the results and presents a list of influencing factors of the RSIS. Chapter 8 gives the comparison of the case-study region with the New World wine region: California. In chapter 9 the research is concluded and the research question is answered. Chapter 10 discusses the theoretical framework, methodology and results.

2. Theory

The aim of this research is to create a better understanding of how the regional and sectoral innovation system is supporting or hindering the implementation of sustainable wine production in the Porto and Douro wine region. In this study sustainable wine production is considered by the following definition, Tseng, 2013:

"*Sustainable production can be defined as (1) the creation of goods and services using processes and systems that are non-polluting, (2) the conservation of energy and natural resources, (3) the practice of economically viable operations, (4) the maintenance of a safe and healthy environment for employees, communities and consumers, and (5) socially and creatively rewarding all working people"* (Tseng, 2013 pp. 47)

For the wine sector, this definition of sustainable production includes three phases of the wine supply chain: viticulture, wine production and wine distribution (Neto *et al*., 2013). In order to support measurability of sustainability, a sustainability performance assessment method is required. Several sustainability assessment tools are presented in literature, specifically designed for agricultural systems. Some examples are the Environmental Management for Agriculture (EMA: Lewis & Bardon, 1998), the Agro-Ecological Indicators (AEI: Girardin *et al*., 2000) and the revised version of AEI: the Indicateurs de Durabilité des Exploitations Agricoles method (IDEA: Zahm *et al*., 2008). These assessment tools are based on indicators connected to the three dimensions in the Triple Bottom Line (people, planet, profit) approach (Pope *et al*., 2004). However, the indicators used in these tools are difficult to scale because they are primarily at a parcel and/or farm level (Van Cauwenbergh *et al*., 2007). The *Sustainability Assessment of Farming and the Environment* (SAFE) framework provides a balanced amount of essential criteria based on the three principles that connect three levels: parcel, farm and regional (Van Cauwenbergh *et al*., 2007). The added regional level in this framework is important for this research. The model by Van Cauwenbergh *et al*, as seen in figure 2, provides a hierarchical analytical framework to facilitate the formulation of sustainability indicators and is based on the work of Lammerts van Bueren and Blom (1997). The overall goal in this case is ''a sustainable wine sector in the Porto and Douro region''. The corresponding principles are general conditions that are necessary for achieving sustainability. These lead to criteria that are the resulting state when the related principle is respected (Van Cauwenbergh *et al.,* 2007). Compliance with the criteria is scored by a yes or no (Van Cauwenbergh *et al.,* 2007). To verify whether the criteria are being met, indicators and reference values are established. To measure these indicators, modelling and calculation procedures are required, but they can also be 'trend-based', meaning that in certain cases a descriptive approach is sufficient (Van Cauwenbergh *et al.,* 2007). An overview of agricultural sustainability criteria is presented in appendix 1.

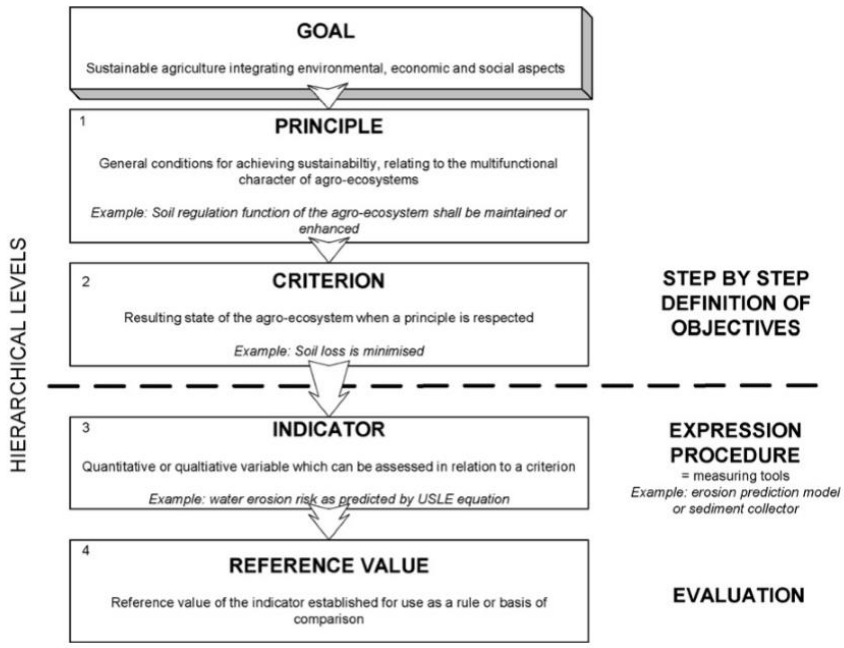

Figure 2. The Sustainability Assessment of Farming and the Environment hierarchical framework (Van Cauwenbergh et al., 2007).

A sustainability transition is defined as the *''fundamental transformation towards more sustainable modes of production and consumption''* (Markard *et al*., 2012, pp. 955). A sustainability transition in the wine region potentially comprehends the transformation of the environmental, social and economic performance.
The transition to a more sustainable wine sector within the EU (Old World) is expected to be driven by the intensifying of public-private regional knowledge transfer which would strengthen the innovative capabilities of the region (Gerstlberger, 2004). In such an innovation system, innovation is seen as a non-linear, evolutionary and interactive process (Tödtling & Trippl, 2005). Essential in this process is the intensive communication and collaboration within and with all actors, such as companies, universities, innovation centres, financial institutions, public institutions and governments (Tödtling & Trippl, 2005). The dependence of knowledge sharing in innovation systems also becomes clear in the definition of innovation used by Plessis (2007).

''Innovation is the creation of new knowledge and ideas to facilitate new business outcomes, aimed at improving internal business processes and structures and to create market driven products and services. Innovation encompasses both radical and incremental innovation.'' (Plessis, 2007 pp. 27).

The concept of an innovation system was first introduced by Christopher Freeman (1987) as:

''*The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies''* (Freeman, 1987; OECD, 1997 pp. 11)

Innovation systems can be approached at different levels, such as the national (Freeman, 1987), regional (Cooke, 1997; Morrison & Rabellotti, 2006), and the sectoral (Cusmano *et al.*, 2010). The regional level of an innovation system (RIS) has gained in interest because regions have a unique history when it comes to political, cultural and economic developments (Cooke, 1997). Also, regions act as one functional area that can be studied with more loose geographical boundaries (Asheim & Coenen, 2006; Boschma, 2004; Cooke *et al., 1997*). Pekkarinen and Harmaakorpi (2006) described the RIS as follows:

''*The Regional Innovation Systems (RIS) consists of different innovation networks aiming at increasing the innovativeness of the regional innovation environment* (…) [they] *are often formed from a heterogeneous group of various actors including representatives of firms, universities, technology centres and development organizations. The ability to interact in these networks becomes a decisive success factor in promoting innovative capability''* (Pekkarinen & Harmaakorpi, 2006 pp. 402).

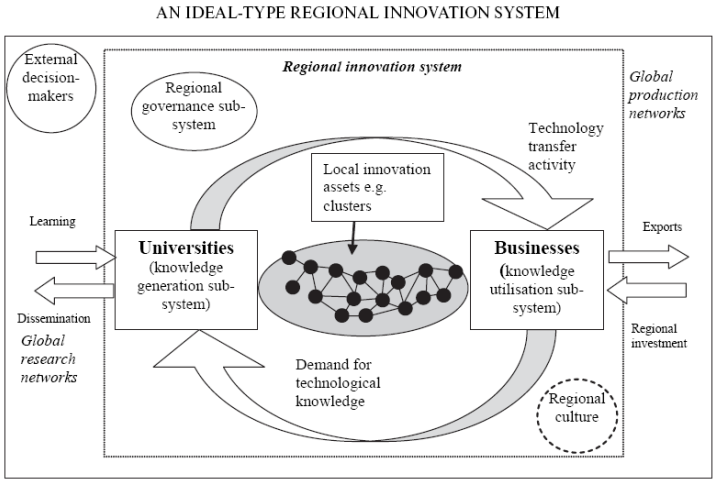

Figure 3. An example of an ideal RIS (Parliament,2009).

Figure 3 represents an 'ideal' model of a RIS (Parliament, 2009). The knowledge transfer between the involved actors is presented centrally, with other characteristics being present such as regional governance, and the regional culture. When studying the RIS, three elements are important in the functioning of the innovation system (Cooke, 1997). First of all, the *financing* of the configuration of a regional innovation system is important. Mainly the *regional budget* determines it's potential (Cooke, 1997). Also, the *financing of infrastructures* such as communication infrastructures, play an important role in the element *financing* (Cooke, 1997). Secondly, the systemic elements of *learning and innovation* are important. Central in this is the cooperation between actors in research networks, industry clubs, or similar cooperation's, as innovation and learning are closely linked (Cooke, 1997). Another important aspect of knowledge transfer is the role of *personal interactions* (Morrison & Rabellotti, 2009). Thirdly, the productive culture, i.e. the element *institutional setting* is important. Certain cultural traits support the ability to develop an innovation process efficiently. The presence of these traits (culture of cooperation, coordination and public/private consensus, etc.) makes an RIS more effective (Cooke, 1997). An overview of the RIS factors is shown in table 1.

Table 1. The main elements of the regional innovation system approach (Cooke, 1997).

Regional Systems Approach
Financing - **Regional budgets** - **Financing infrastructures**
Learning and innovation
Institutional framework

But the RIS approach barely considers the *globalization* of production networks and knowledge flows. Considering the increasingly globalized wine industry regarding the upcoming New World wine regions, this globalization of networks and knowledge is becoming increasingly important to wine regions. The Sectoral System of Innovation (SSI) approach does consider this globalization of production networks and knowledge flows at the sectoral level, as this is an important element in terms of innovation dynamics that create opportunities through which laggards (Old World wine regions) can catch up on new sustainable wine production methods (Cusmano *et al*., 2010). Cusmano *et al.* (2010) describe the SSI approach as follows:

''*The Sectoral System of Innovation (SSI) approach focuses on co-evolutionary mechanisms on the demand and supply side. (…) it identifies the key elements that are different and specific to each industry and emphasizes the international, national, and local conditions that can amplify or hinder the sector-specific evolutionary mechanisms.''* (Cusmano *et al.*, 2010 pp. 1589-1590)

When using such a SSI approach to study an innovation system, four interrelated elements are of importance (Cusmano *et al*., 2010). Some of these elements are very similar compared to the RIS factors but have to be considered at global and sectoral level (Cusmano *et al*., 2010). The first element includes the *knowledge domains,* which are the main scientific and technological actors which provide the essential knowledge to undertake innovative activities (Cusmano *et al*., 2010). Secondly, *demand* is essential for the existence of an SSI. Demand provides the incentives to innovate because demand, in general, is an important stimulus to change, but can also provide a constraint to innovation (Cusmano *et al*., 2010). Thirdly, the *key actors and their relationships* are an important element in the SSI. Actors such as universities, governments, institutes, trade unions and firms play a vital role in the SSI (Cusmano *et al*., 2010). Fourthly, the *institutional framework* is an important element in the SSI (Cusmano *et al*., 2010). It is similar to the institutional framework in the RIS (Cooke, 1997), but encompasses also the laws, standards, and norms that influence the interactions between agents (Cusmano *et al*., 2010). Both the RIS and the SSI approach contain important factors to understand innovations in the regional and sectoral innovation system. Table 2 presents the main sectoral system of innovation (SSI) elements.

Table 2. The main elements of the sectoral system of innovation approach (Cusmano et al., 2010).

Sectoral Systems Approach
Knowledge domains
Demand
Actors and networks
Institutions

With the elements of the regional and sectoral innovation systems outlined, it becomes important to study *how* these elements influence sustainable wine production. Figure 4 shows the conceptual framework with the innovation system components that could support or hinder sustainable wine production. On the top the regional and sectoral innovation system is shown with the actors in separate boxes. Elements of the innovation system are shown in the red boxes; *governance/financing*, *culture* and the *institutional framework*. In the green boxes are the (international) *knowledge domains* and in the blue boxes are the *businesses* involved in wine production and wine distribution shown. The functioning of this innovation system is dependent on the composition of actors, the actor-network relationships, financing of the innovation environment and the institutional framework (Cooke, 1997; Cusmano *et al*., 2010). Sustainable wine production is characterized by their contribution to a better sustainability performance which in turn can be measured by the SAFE frameworks indicators as shown in the bottom part of the conceptual framework.

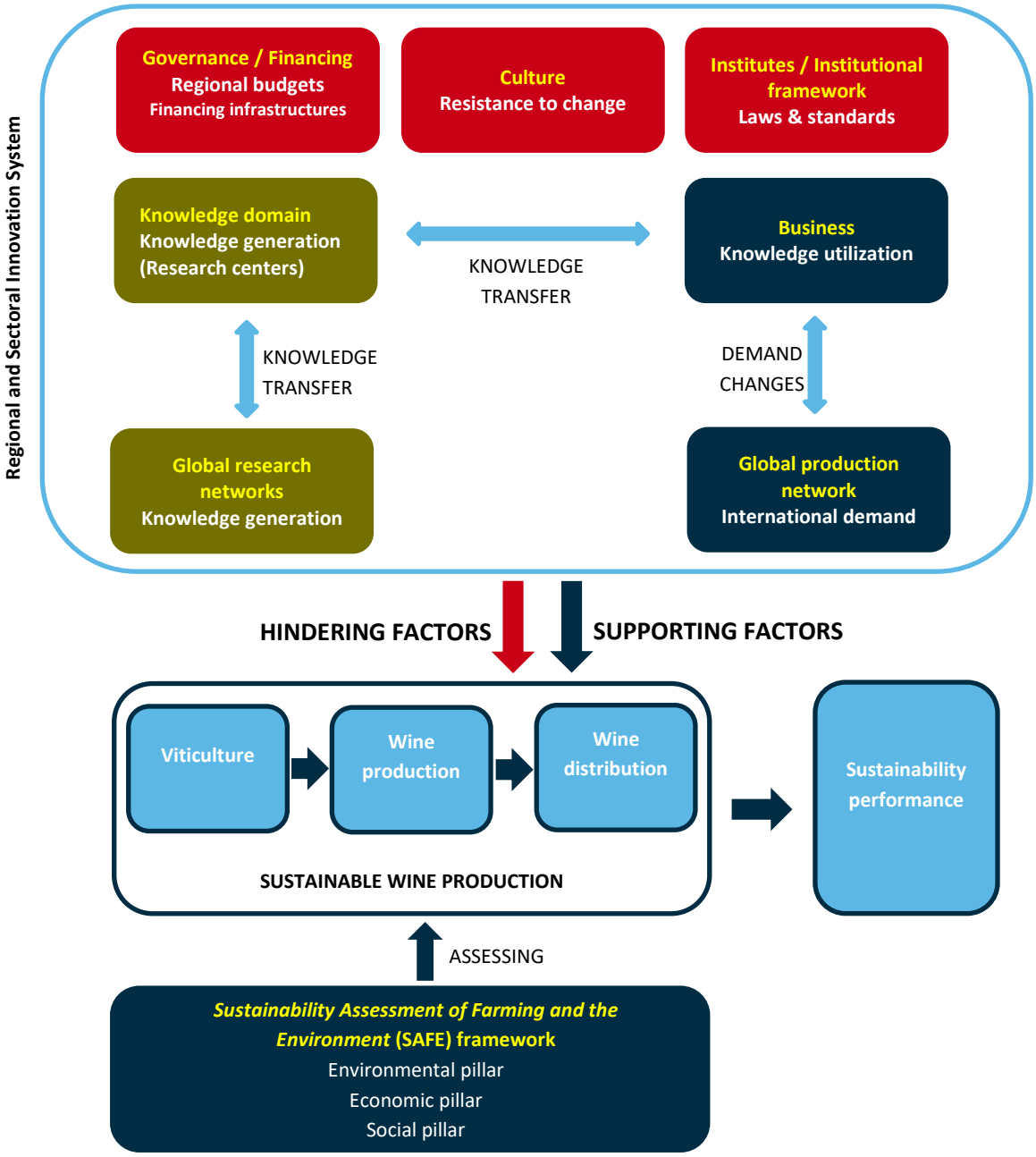

Figure 4. The conceptual framework including the elements of the RSIS in one model supporting or hindering the sustainable wine production in the Porto and Douro wine region, based on figure 3, and table 1 and 2. The RSIS is indicated above, with red, green and blue boxes. The red boxes show the actors that determine the innovation system environment, such as the culture, governance and the institutional framework. The green boxes show the knowledge domains, both regional and international. The blue boxes show the business actors, both regional and international. This RSIS potentially influences the sustainable wine production in the region through supporting or hindering factors. The boxes below the RSIS is the resulting sustainable wine production, which involves the whole supply chain: viticulture, wine production and wine distribution. The relevance of these factors to sustainable wine production is assessed with the use of the SAFE framework.

Theoretically approached, it is expected that better and more financing, a general culture of cooperation within the innovation system actors, the presence of multiple knowledge domains with connectedness to all actors and networks, and a dynamic demand all will support sustainable wine production (Cooke, 1997; Cusmano *et al.,* 2010). Likewise, it is expected that low financing, a culture of non-cooperation, the absence of knowledge domains or the presence of knowledge domains but without the connectedness to actors and networks, and a non-changing demand will be hindering factors to sustainable wine production (Cooke, 1997; Cusmano *et al.,* 2010)..

3. Methods

The method part discusses the research design, data collection, data analysis and the quality of the research (validity and reliability of the applied methods).

3.1 Research Design

For this research, a case study design was used since the contextual conditions are relevant to the phenomenon under study (Baxter & Jack, 2008). A case study entails a detailed and intensive analysis of one delineated case (Yin, 2013). Due to the explorative, qualitative nature of this research, the data can be triangulated, and a variety of information sources including documentation and interviews can be combined, which lead to increased validity (Yin, 2013). The research question aims to gain insight on how the RSIS supports or hinders sustainable wine production in the Old World (i.e. Europe and other historic wine regions) Porto and Douro wine region. Next to this, the RSIS of a New World (i.e. emerging wine regions like New Zealand, California, South Africa and Australia) region has been explored through literature study to find possible lessons regarding factors influencing sustainable wine production. Lastly, based on the findings of the identified hurdles to sustainable wine production recommendations are be presented on which strategies can be designed to transform the Porto and Douro wine region to a more sustainable wine region.

For this qualitative explorative research the UNESCO certified case-study region 'Porto and Douro, Portugal' has been selected (UNESCO, 2016). For the purpose of this research, the author was positioned as an intern at the host organisation IVDP (*Instituto dos Vinhos do Douro e Porto*), which is the wine institute of the regional wine sector. Here, wines are certified on quality and authenticity before they are released on the market. The country is currently considered as 'late majority' on environmental policies (Knill *et al*., 2012).

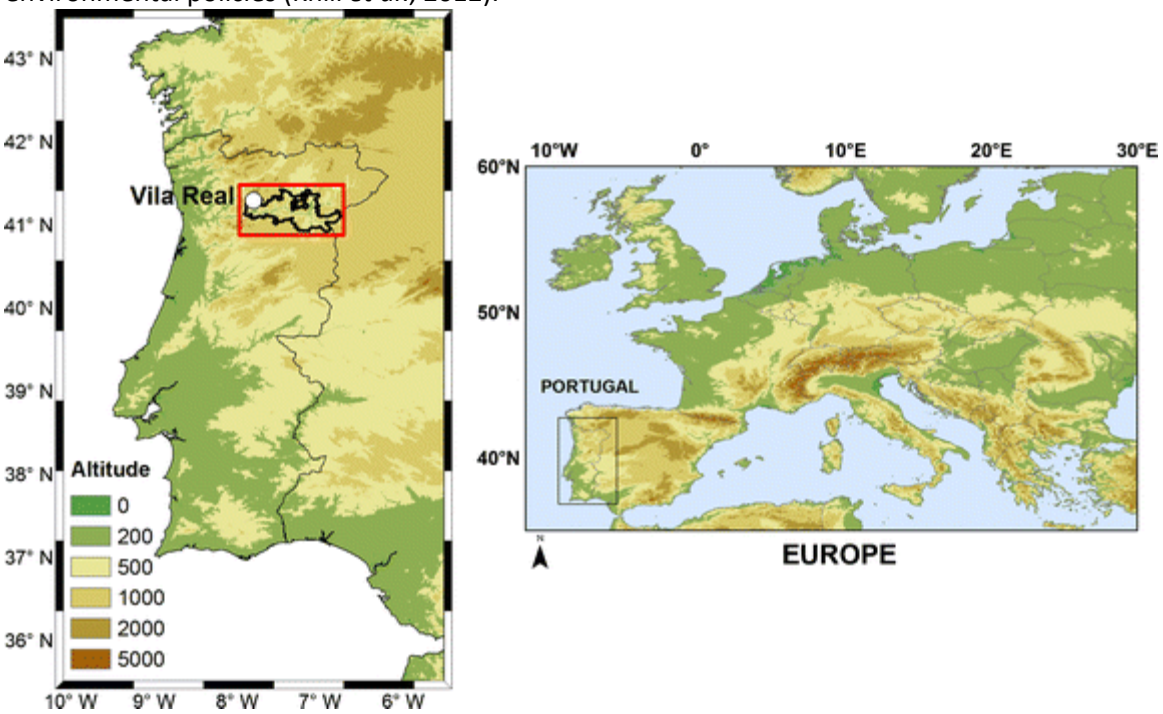

Figure 5. The Douro valley indicated on the map of Europe (right image) of the west side of the Iberian peninsula (left image) with a general altitude indication (Santos *et al*., 2013).

The Douro valley (figure 5) yields 60 to 90 million litres of port wine on a yearly basis (IVDP, 2016). In this region work roughly 20.000 workers and approximately 100 wine producers use grapes from the Douro valley to produce their port wines (personal communication IVDP, 2016). A life cycle assessment has been executed on the supply chain of a Portuguese wine from a nearby wine region (Neto *et al*., 2013) and the effects of climate change on the wine production has been researched in

the Douro valley (Jones & Alves, 2011). Neto *et al.,* and Jones & Alves identified multiple environmental sustainability issues, such as soil degradation, biodiversity loss, pollution and they mentioned social sustainability issues such as poverty and low degree of education (Jones & Alves, 2011; Neto *et al.*, 2013). Because of the lack of published sustainable wine production methods and the presence of locally executed sustainability related studies, this region is ideal for a case study region.
As a first research step, the conceptual model was operationalized by interviewing three experts, one from the wine sector business domain and two from the agricultural knowledge domain. In this way, key actors were identified that needed to be included in the research. Secondly, actors, such as institutes, policy-makers, wine producers, farmers and research organisations, within the regional wine sector innovation system were interviewed through semi-structured interviews. The aim was to interview at least 2 people per box (of the conceptual framework) so that data could be cross-referenced to increase reliability. A draft of the interview questions can be found in appendix 2.

For the New World wine region exploration, a region had to be selected. Extensive literature exists on sustainability programmes in New World wine regions (Alonso & Liu, 2012; Beske *et al*., 2014; Carter & Easton, 2011; Comandaru *et al*., 2012; Delmans & Lessem, 2015; Dodds *et al*., 2015; Flint & Golicic, 2009; Gabzdylova *et al*., 2009; Jones & Alves, 2012; Pullman *et al*., 2010; Santini *et al*., 2013; Vecchio, 2013; Zucca *et al*., 2009). Four New World front-runners in sustainable wine production have been identified, along with their sustainability programmes for sustainable wine production; the California Sustainable Winegrowing Alliance (CSWA), Sustainable Australia Winegrowing (SAW), Sustainable Wine South Africa (SWSA) and the Sustainable Winegrowing New Zealand (SWNZ) (Personal communication dr. Walter Vermeulen 23-01-2016).

As the New World wine region could not be visited personally, documents and scientific literature on the region was key to understanding the factors of the New World RSIS affecting the sustainable wine production. Therefore, the New World RSIS with the most exact hits on Google Scholar was selected for this research (Search terms used: ''California Sustainable Winegrowing Alliance'', ''Sustainable Australia Winegrowing'', ''Sustainable Wine South Africa'', and ''Sustainable Winegrowing New Zealand''. Furthermore, the availability for a Skype interview with one of the representatives of the sustainable wine production programme was also of great importance.

California Sustainable Winegrowing Alliance:	**127 hits**
Sustainable Australia Winegrowing:	3 hits
Sustainable Wine South Africa:	14 hits
Sustainable Winegrowing New Zealand:	**154 hits**

Because the sustainable wine production programme of New Zealand appeared unresponsive to contact requests, and California was willing to share information through an interview, the RSIS of California has been explored regarding supporting and hindering factors to sustainable wine production.

3.2.1. Data collection – Porto and Douro region

To gain insight in all factors in the innovation system, it was necessary to map the actors and networks of the RSIS first. These actors were revealed through semi-structured interviews. An interview with two researchers related to sustainable wine production in the Porto and Douro region were scheduled. Also a senior manager of the largest wine company has been approached for an interview at this stage. Once the actors and networks were identified, semi-structured interviews were scheduled with people involved in policy-making, sustainability practices, supply chain managers or the person most closely related to the topic. Per actor at least two semi-structured interviews were carried out to increase the validity and reliability of the results. A list of interviewees is presented in table 3 .The purpose of these interviews was to gain insight in how the factors of the

regional wine innovation system are hindering or supporting sustainable wine production. The interviews were based on a question list based on the operationalized conceptual model and the SAFE framework for assessing sustainability performance (Van Cauwenbergh *et al.*, 2007). All interviews were double recorded and transcribed and coded with NVIVO 11 for Windows. It is important to use multiple data sources for more robust results (Baxter & Jack, 2008). Therefore this information has been complemented with observations and with scientific literature on the Douro valley, annual reports, sustainability reports, public sources and documents available at the IVDP. The transcripts of the interviews are available on request.

Table 3. The performed interviews in the Porto and Douro wine innovation system.

Interviewee	Position	Company/institute	Interview location	Date
IV1	Postdoctoral researcher	UTAD[1]	Vila Real	16-05-2016
IV2	Professor Environmental Engineering	University of Aveiro	Porto, FEUP	02-06-2016
IV3	Top manager	Sogrape Vinhos, S.A.	Porto, IVDP	03-06-2016
IV4	Research Fellowship	INEGI[2]	Porto, INEGI	17-06-2016
IV5	Project Manager	INEGI	Porto, INEGI	17-06-2016
IV6	Administrator	Duorum Vinhos	Porto, Foz	15-07-2016
IV7	Program Director	CSWA[3]	Skype	10-08-2016
IV8	Viticulturist	Muxagat Vinhos	Vila Nova de Foz Côa	12-08-2016
IV9	Viticulturist	Ramos Pinto	Vila Nova de Foz Côa	12-08-2016
IV10	Technical & Certification Director	IVDP[4]	Porto, IVDP	16-08-2016
IV11	Sustainability Manager	WASP[5]	Skype	16-08-2016
IV12	Viticultural Manager	Quinta dos Murças	Covelinhas	26-08-2016
IV13	Senior Government Official	IVDP	Porto, IVDP	31-08-2016
IV14	Consultant & Co-Owner	Inkwell Wines	E-mail	22-08-2016
IV15	Coordinator of the Knowledge Center	IVDP	E-mail	13-09-2016

1 = University of Trás-os-Montes and Alto, 2 = Institute of Science and Innovation in Mechanical and Industrial Engineering, 3 = California Sustainable Winegrowing Alliance, 4 = Instituto dos Vinhos do Douro e Porto, 5 = Wines of Alentejo Sustainability Programme

3.2.2. Data collection – New World region

To gain insight in the factors stimulating or hindering sustainable wine production in California, a remote explorative case study has been executed. The data on the California wine region was collected through an extensive literature review (search terms used: ''CSWA'', ''California Sustainable Winegrowing Alliance'', ''Sustainable wine production California''). Available public documents, websites and sustainability reports of local companies have been examined. Additional data was gathered through a Skype interview with the program director of the California Sustainable Winegrowing Alliance. The Skype interview was semi-structured and recorded using a call recorder program. Through these ways, insight was gained into the factors influencing sustainable wine production in California.

3.3 Operationalization

The RSIS has to be operationalized in order to identify influencing factors of the RSIS on sustainable wine production. The RIS and SSI theories have been used to set up a preliminary list of elements, as presented in the left column of table 4. The corresponding factors are described in the right column of table 4, based on descriptions of Cooke (1997) and Cusmano *et al.*, (2010). Additional factors that were used for coding were later added in the category 'other'.

Table 4. The RSIS factors including factors mentioned by Cooke (1997) and Cusmano et al*. (2010) on the functioning of the innovation system and others, as identified relevant during the interviews.*

Elements	Factors
Financing budgets	Factors related to the financial situation of the innovation system, such as budget size and taxes.
Financing infrastructures	Factors related to the influence on design and execution of basic infrastructures, such as railways and telecommunication networks.
Learning and Innovation	Factors related to the learning environment of the innovation system, such as a 'willingness to cooperate'.
Institutional framework	Factors related to the cultural traits of the innovation system.
Knowledge domains, learning processes & logistics	Factors related to the connectedness of knowledge domains, such as universities, to the innovation system.
Demand	Factors related to demand changes, specifically on sustainable wine production.
Actors & networks	Factors related to the relationships between key actors of the innovation system.
Institutions	Factors related to regulations, certification, standards with regard to wine production and distribution.
Other	Factors that are not related to any of the elements mentioned above, for example entrepreneurship.

In the second part of the conceptual model (bottom half), the implementation of sustainable wine production has been assessed using the SAFE analytical framework (Van Cauwenbergh, 2007). This framework provided the baseline of sustainability measurement in this research. Environmental, social and economic dimensions are the foundation of this framework, which is proved to be suitable for the wine sector as it has been used more often (Pullman *et al.*, 2010). The framework provides criteria for sustainability assessment on all sustainability pillars, but the corresponding indicators are retrieved from Sauvenier *et al*., (2006) pp. 25-31 (appendix 3). The SAFE framework indicator list is cross validated with additional sources, to test validity and completeness. Additional data is retrieved from wine related LCA studies (Pizzigallo *et al*., 2008; Pattara *et al*., 2012; Comandaru *et al*., 2012; Point *et al*., 2012; Neto *et al*., 2013). The studies done by Mascarenhas *et al*., 2010; Pullman *et al.*, 2010, Slaper & Hall, 2011 and Jones & Alves, 2011 also provide the necessary indicators for sustainable wine production. See appendix 4 for an overview of the cross validated indicators from the LCA related wine studies.

3.4 Data analysis

The semi-structured interviews were recorded and transcribed. The interviews with the RSIS actors were analysed by using the identified elements (table 4) in the conceptual model to detect mechanisms that hinder or support sustainable wine production of the regional wine sector. The interviews were structured along the different innovation system elements that can play a role in sustainable wine production. A coding scheme has been developed based on table 4. Categories of this coding scheme are based on elements from table 4 that support or hinder sustainable wine production. The coding categories are presented in appendix 6. The recorded interviews were coded with the use of NVivo 11. Extra caution was given to potential hidden themes, indicators or mechanisms influencing the sustainable production of the wine region. By finding the RSIS factors influencing sustainable wine production in each case (Portugal and California), and cross validating these with different data sources, general trends became distinguishable.

3.5 Validity and reliability of the research

Validity refers to whether the observations, identifications or measurements are in line with the research and how well conclusions drawn from a particular study. Reliability refers to the consistency of what is observed, identified or measured (Yin, 2013). To ensure the construct validity of the study, data has been triangulated with multiple sources. Various scientific experts on the sustainability issues in the Porto and Douro region were interviewed to increase the validity (IV 1; IV 2). Regarding internal validity, this study is less prone to losing validity since the nature of this study is descriptive and presenting report findings and interview findings. Regarding internal reliability, the recordings and transcripts of interviews are available for second readers, unless otherwise desired by any of the interviewees. The interpretation of data has been executed by one researcher, but cases of doubt have been discussed with supervisors.

4. Case description

First, a brief overview of the wine history of the Porto and Douro region is given, as many characteristics of the Porto & Douro wine region are the result of developments in the past. Then, the current supply chain in the Porto & Douro wine sector is presented to create insight in the size and quantities of the Porto & Douro wine region.

4.1.1 Porto and Douro viticultural history

Carbonized grape pits have been found in archaeological sites in the Douro region, indicating that vine was already being cultivated 4000 BCE (Dourovalley.eu, 2016). The first evidence of viticultural activity in the mountainous region of the Douro was documented by the Romans during their occupation of the Iberian Peninsula from 27 BCE (Paulo Martins, 2011; Taylor, 2016). By the middle ages, vineyards were found throughout Portugal. Together with cereals and olive oil, wine was one of the pillars of rural economics (Paulo Martins, 2011; IV 8). The Douro region was in this stage always very poor and underdeveloped (Paulo Martins, 2011; IV 8; IV 9). The 18th century is considered a dividing line between this, less significant viticultural era, and the upcoming age of wine export (Taylor, 2016). The pattern of rural economies underwent a massive alteration, the landscape was modified and social relations were transformed. This was sparked by the wars between British and French kings, the British boycotted wine products from France and were therefore looking to secure their wine supply (Taylor, 2016). At around the year 1750 British merchants were responsible for about 60% of Porto's trade in wine, 35% was due to Portuguese traders and the remaining trade was in the hands of German, French and Dutch merchants (Paulo Martins, 2011). At this point agricultural monoculture of vine took over in the Douro as wine prices kept rising. Today, still all the vineyards are typically monocultures (IV8). This led to a vast increase in production of vine in the Douro. Prices dropped with about 90% (Paulo Martins, 2011; Taylor, 2016). As one of the government interventions, the Demarcated Douro Region (DDR), as illustrated in figure 8, was formalized to stop the uncontrolled expansion (Taylor, 2016). In 1756, after a couple of bad wine years, Port wine traders started looking elsewhere for their wine supply. This was one of the reasons for the foundation of the Companhia General da Agricultura das Vinhas do Alto Douro, or in short 'Companhia'. Among this government entity's responsibilities were; to encourage vines cultivation in the Douro, to control the price, to safeguard its authenticity and to address the monopoly of the British traders whom were dictating the Portuguese farmers. Because of this development, the oldest demarcated and controlled wine region in the world was born (Taylor, 2016). It didn't take long for the Companhia to be contested by the Portuguese farmers as it heavily controlled rules of behaviour such as the methods used for wine making and the price used (Paulo Martins, 2011). In the beginning of the 19th century, wine traded from Porto represented 80% of all the Portuguese wine export, and demand was evermore increasing due to conflicts between Britain and France (Paulo Martins, 2011). Most British firms were well established in the port trade by now. Few totally new port houses established later on. The first 20 years of the 19th century meant turbulent years for Portugal, politically and militarily (Taylor, 2016). The combination of a freer trade as pressured from the British, and a liberal movement in the politics, meant that the Companhia was reorganized in 1843 and later abolished in 1863 (Paulo Martins, 2011; Taylor, 2016). Prices of wine dropped again now that the authority of the Companhia was gone. Many new vineyards were planted without control or attention to quality (Paulo Martins, 2011). It was during this time (1851) when the first plague, *oidium*, hit the viticultural sector in the Douro. Production lowered with about 50%, but exports remained the same (Paulo Martins, 2011). The productive sector was reorganized, demonstrating the burden on farmers and not the traders during natural catastrophes (IV 8). Shortly after this plague in 1863 a second plague, *phylloxera*, hit the viticultural sector in the Douro. The tiny insect had come along North American vines that were being imported. The North American vines were immune to the insect, but the vines in the Douro were not (Taylor, 2016). The only way to effectively combat this plague was to plant more American vines that were immune to the microscopic insects. Even today there is no other way to counter these insects. Almost all vineyards

are domestic vines on American rootstocks (Paulo Martins, 2011; Taylor, 2016). In 1893, a third plague hit the viticultural sector. This time it was *mildew*, it was not as destructive as *phylloxera* because it could be countered by spraying a sulphur based mixture. These pests greatly affected the farmers in the Douro, but the impact on the trade was less significant due to large stocks of wine. It was the merchants in Porto who benefitted the most as they were able to increase their influence in the Douro by purchasing quintas (Paulo Martins, 2011; IV 8; IV 9). The social organization and the relations changed drastically. The people in the Douro paid the biggest price, vast areas of vineyards were abandoned and they had no more grapes to sell. New groups and farmers with sufficient wealth appeared on the scene, quintas changed hands and new vineyards were planted (Paulo Martins, 2011). Firms that were only exporting wine became interested in ownership of vineyards in the Douro region. The demarcated region was expanded and a railway line was realized from Porto to the now more accessible Upper Douro (IV 8). The consequences of these three plagues on agricultural practices was also noticeable. From now on, treatment against mildew and oidium became mandatory (Paulo Martins, 2011; IV 9).

In the 20th century the wine sector in Portugal endured on one hand a rush of protectionism from the government, but also the desire for free trade on the other hand. It was under the new Portuguese dictatorship that started in 1926 that several regulating entities were founded to control the Douro region. In 1932 the Caso do Douro was created, and in 1933 the Port Wine Institute (now IVDP) and the Port Wine Shippers Association (AEVP) were created (Paulo Martins, 2011). In 1942 the certifying label was introduced to guarantee origin and authenticity of the port wine. During World War Two, the vineyards were registered with the use of parameters from the Beneficio system. This is a parameter set used to evaluate vineyards that works on a point system. With this system, grapes are better sorted according to quality of the vineyard (Paulo Martins, 2011). During World War Two, port export drastically decreased and smaller port houses were suffering. It was during this period that larger export companies took over many smaller ones (Taylor, 2016). In 1964 the government authorized transport of wine from the Douro to Porto by road, as only river and train transport were allowed until then. At this point transport in containers became more frequent rather than wooden barrels. Originally wines were sold in bulk, but an increase was visible in port wine being sold in bottles. In 1996 selling of port wine in bulk became prohibited in all port wine categories, so that Portuguese producers gained more control over the final product (IV 10). Farmers were also no longer dependent on the shippers to sell their wines. Now, they are able to sell their production to shippers, sell their own wine under their own label and make still wines of grapes that were licensed for port wine (Paulo Martins, 2011; IV8). To accommodate the interest of the shippers and the farmers, the Portuguese government created the Committee for the Demarcated Douro Region (CIRDD). Now it is known as the Interprofessional Committee and is under the IVDP, consisting of half representatives of the farmers and half representatives of the merchants (Paulo Martins, 2011; IV 10; IV 13).

Today, a tendency for a concentration of interests is observed. A very small amount of port wine companies in Porto own a very large share of the port wine market. The Portuguese companies Symington, Sogrape, Porto Cruz, Taylor/Fonseca, Sogevinus and Companhia velha are ruling the Porto & Douro (port) wine market (Paulo Martins, 2011; IV 8; IV 9).

To sum up, the Porto and Douro wine region is characterized by a long series of events through history, which unquestionably influence current day's policies and culture of the region. The three plagues have might influence today's view on pesticide use in the Porto and Douro region, and the concentration of market share on an ever smaller amount of companies

4.2 Porto and Douro wine supply chain

This section discusses the current day supply chain of the Porto and Douro wine sector. This is done following the three steps from vine to wine as they are described by Neto *et al*., 2013 and Paulo Martins, 2011: viticulture, wine production and wine distribution (figure 6). Most numbers are retrieved from the IVDP and are of the year 2015 unless otherwise specified. The viticultural stage is further elaborated in part 4.2.1, wine production is further elaborated in part 4.2.2 and wine distribution is further elaborated in part 4.2.3.

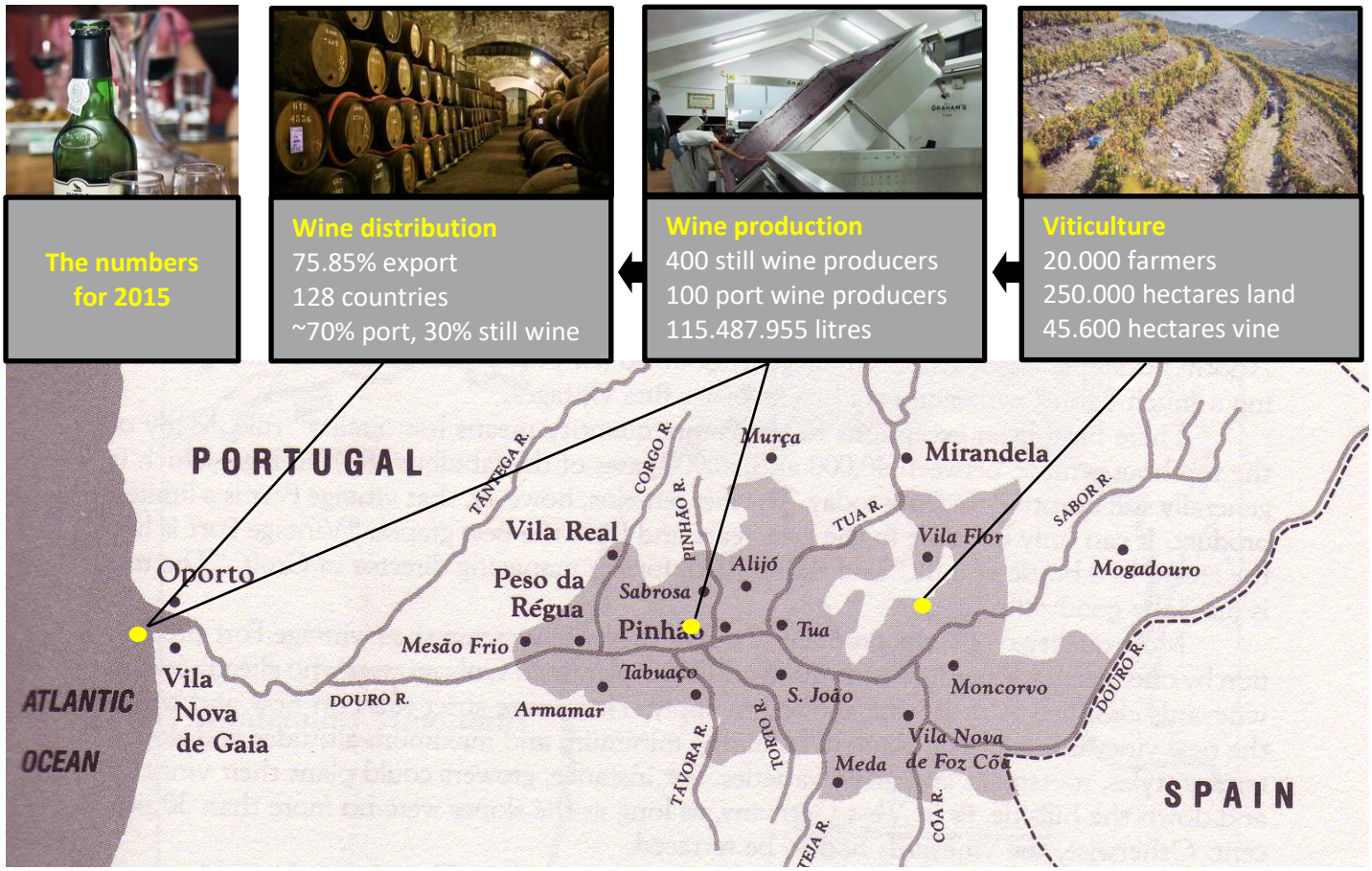

Figure 6. A representation of the supply chain of the Porto & Douro wine sector. The dark grey area on the right, bordered by Spain, is the Douro region. This is where the viticulture is found and part of the wine production. Oporto is the harbour city where this wine was also produced out of grapes from the Douro region, but mostly it was just here for storage and export. Vila Nova de Gaia is the city on the opposite side of the river where these days all the port wine houses are located due to the better suitable climate and historic events.

4.2.1 Viticultural stage

The vineyards are situated in the Douro valley. Here, approximately 20.000 farmers work on the vineyards (IV 10). The area is about 250.000 hectares of land, but only about 45.600 hectares is used for viticulture (Paulo Martins, 2011). The main soil type of the Douro region is schist, which makes it so suitable for viticulture. It can hold water and it allows the roots to dig into the subsoil. The region is divided in three sub regions; Lower Corgo, Upper Corgo and Upper Douro (Baixo Corgo, Cima Corgo and Douro Superior in Portuguese) (figure 7). The sub regions distinguish themselves through their differences in climate and specific soil types (Paulo Martins, 2011).

The Lower Corgo has the greatest number of vines, 45.000 hectares and about 14.500 under vine (Paulo Martins, 2011). As it is closer and better connected to Porto, this region was the first to start producing port wine for the merchants. It also has some larger cities such as Vila Real and Regua. This

region sees most of the rainfall, with the most centralized city Peso da Régua receiving 970mm (Climate-data.org, 2016). Partly due to this, no vineyard in the Lower Corgo has the highest rating of A in the Beneficio evaluation scheme. Therefore, it is no longer the main area where grapes are grown for port wine.
The Upper Corgo covers an area of 95.000 hectares, with about 21.000 in vine. The region is characterized by steeper hills and a more rocky environment. It is here where most quintas are that produce for the port wine companies. They are more suitable for higher quality because of the climate. The cold winters and hot summers are key to producing quality grapes. During the year, Pinhão receives 870mm of average precipitation (Climate-data.org, 2016).
The Upper Douro is the area where generally the newest vineyards are. This region covers 110.000 hectares, but only 10.200 of it is covered with vine. It was not a region of general interest until quite recently, because of the great distance from the merchants in Porto and the bad connectivity (Paulo Martins, 2011). Nowadays this part of the region has many benefits from the other sub-regions. The lands are more flat so the vineyards are easier to mechanize, there is considerable less rainfall which greatly reduces the need for pesticides and the lands are of lower price (IV 1). Vila Nova de Foz Côa, receives an average of 835mm of precipitation on a yearly basis (Climate-data.org, 2016).

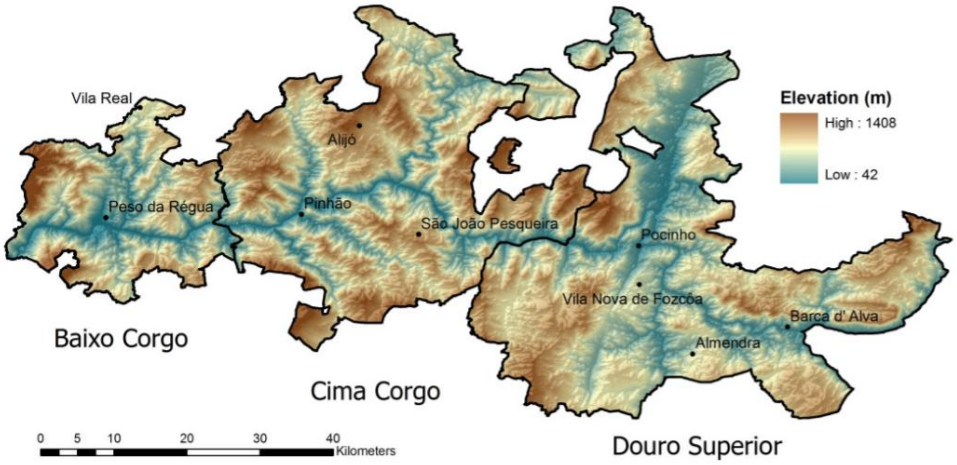

Figure 7. The Douro valley with the elevation indication. Shown are the three main sub-regions, Baixo Corgo (most western sub-region, 92km east of Porto), Cima Corgo and Douro Superior (Jones & Alves, 2012).

4.2.2 Wine production

Grapes that come from the vineyard during the harvest season have to be processed to turn into a wine. This process is executed at a winery. Quintas often have their own winery, so the wine in this case is produced in the Douro region itself according to a viticultural manager (IV 12). In the winery, grapes are to be crushed, fermented, filtered and aged. For the crushing they originally used so-called *Lagars*, granite tanks where the grapes would be crushed with the feet. Today's equipment for the processes like crushing and storing is often made out of stainless steel, as it is by far the cleanest and safest option regarding bacterial hazards (Paulo Martins, 2011; IV 12). Premium wines are however stored in oak barrels, as it becomes an integral part of the taste of the product over time. Storage of these barrels is usually done in warehouses in or close to Vila Nova de Gaia, close to Porto.

4.2.3 Wine distribution

The Porto & Douro wine trade has been in control of the merchants ever since the early 18th century (Paulo Martins, 2011; Taylor, 2016). Nowadays, around 100 port wine producers exist and 400 Douro still wine producers, according to IVDP data (IV 10). The sector saw a significant decrease in production in response to the 2008 crisis (IV 10). In light of this development, prices of wine remained stable and started increasing ever since 2009. Since then, the total value of the retail has been increasing slightly every year, exceeding 2007 levels last year in 2015. Of the 115 million litres sold in 2015, 37 million was for domestic markets. Portuguese consumption takes 30 to 33% of the total production on a yearly basis (IVDP archives). More information about the Douro wines is presented in figure 8, 9 and 10.

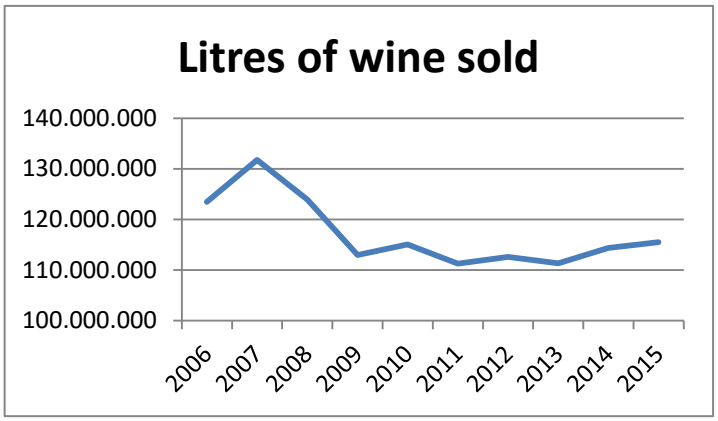

Figure 8. The total wine production in litres from the Douro region in the years 2006-2015 (IVDP archives).

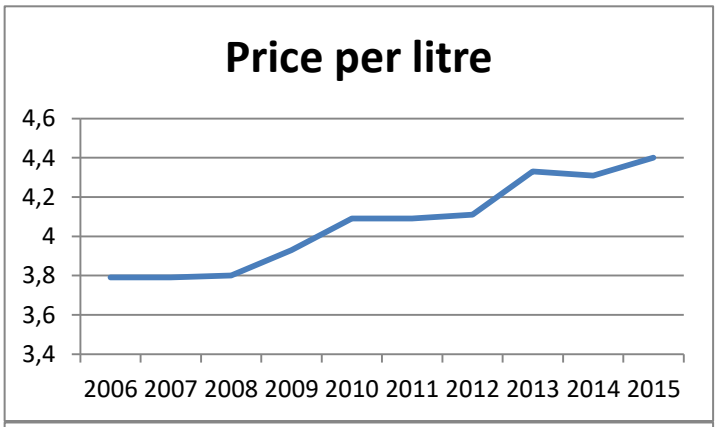

Figure 9. The average price per litre of wine in euro from the Douro region in the years 2006-2015 (IVDP archives).

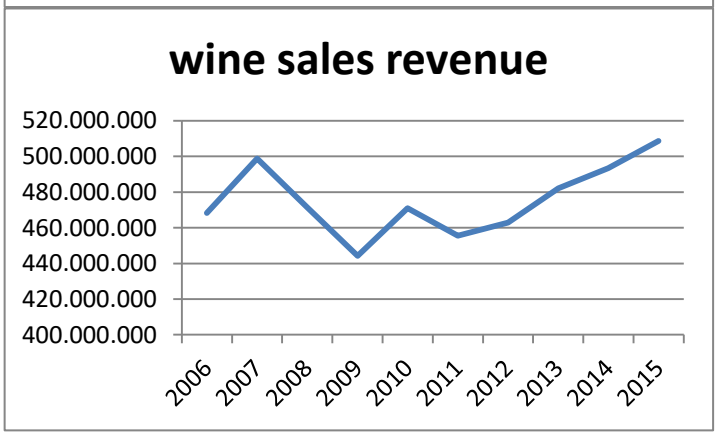

Figure 10. The total revenue in euro of the wine sales both nationally and export of the Porto and Douro region in the years 2006-2015 (IVDP archives).

It is clear that the Porto and Douro wine region is characterized by a unique history on political, cultural and economic developments. Which sustainability challenges the region faces today is further elaborated in chapter 5.

5. Results: Main sustainability challenges of the Douro wine sector

This chapter presents the main sustainability issues of the Porto and Douro wine region. These are the result of a sustainability assessment of the topics discovered during the interviews. These topics are characterized according to the SAFE framework as discussed in chapter 3. Understanding which sustainability challenges the regional wine sector in the Douro faces today, and in the future, is key to shedding light on factors that might be hindering sustainable wine production. After all, once a critical sustainability challenge has been identified, it becomes more practical to determine which innovation systemic factors are supporting or hindering possible solutions to these challenges (figure 11) and hence result in a higher sustainability performance of the Porto and Douro wine region.

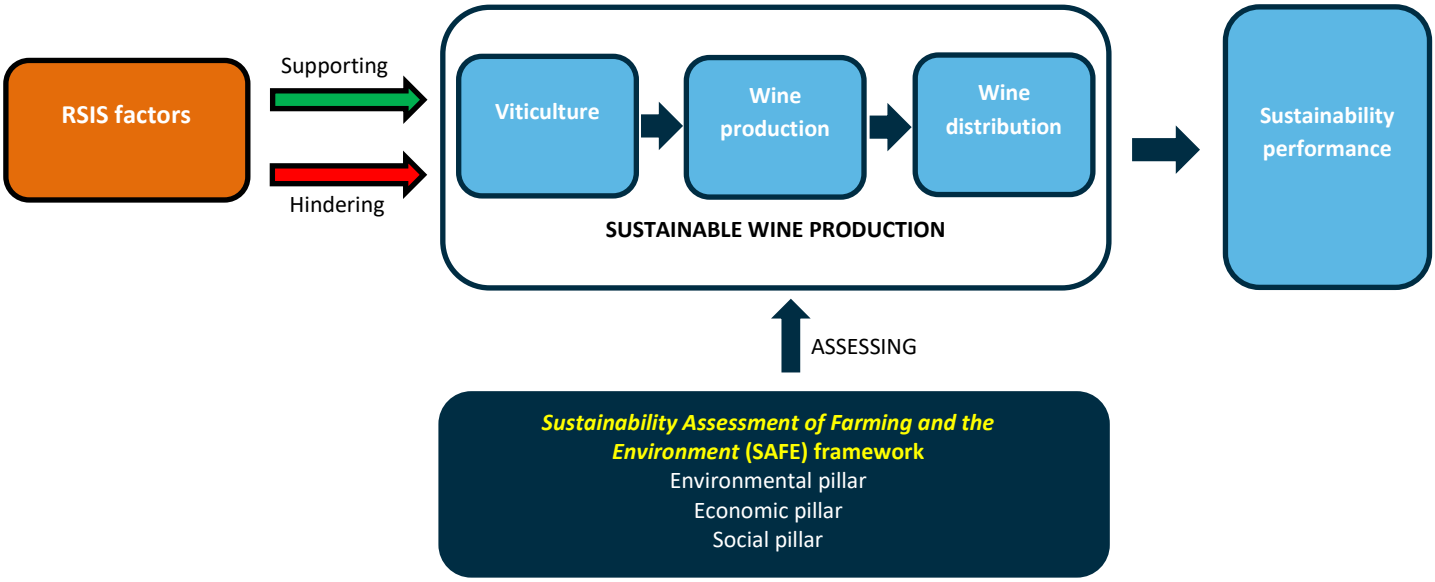

Figure 11. Half of the conceptual model as presented in chapter 2. All innovation system actors, networks and institutional framework have been compressed into 'RSIS factors'.

In the following subchapters, the main sustainability challenges are presented that have been found in the case of Douro wine production. According to the SAFE framework, they have been subdivided according to environmental, economic and social challenges.

5.1 Environmental challenges

A practical tool to map environmental burdens of a product is the use of a life cycle assessment (LCA). In 2012 a study was published of an LCA on a bottle of 0.75L vinho verde as a functional unit (Neto *et al*., 2013). Vinho verde is a type of wine originating from the Minho province, north of Porto. The analysis included the viticultural stage, wine production stage and distribution, but also bottle production is included. One of the authors stated:

''*The contribution of viticulture is always the highest in the life cycle. The distribution stage is not very relevant. If you want to improve the environmental performance we should make changes in the viticulture practices. But this can be difficult.*'' (IV 2)

The findings of this LCA study are presented in figure 12. The main causes of these environmental impacts to the impact categories were the use of fertilizers, pesticides, combustion engines and land (Neto *et al*., 2013).

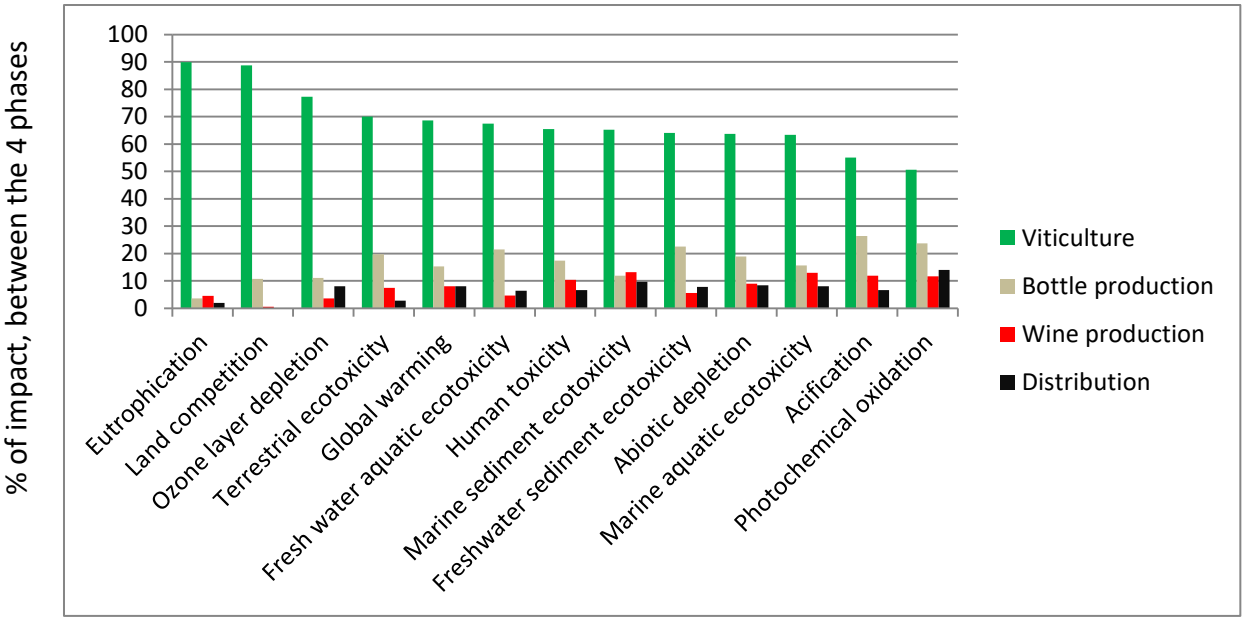

Figure 12. Environmental impact in relative percentage according to thirteen impact categories of the viticulture, bottle production, wine production and distribution stage of a 0.75L vinho verde Portuguese wine as found by Neto et al *(2013).*

A similar scenario is valid for the Douro region as the following challenges were pointed out by the interviewees as the most relevant environmental sustainability challenges; excessive use of pesticides, genetic erosion and water scarcity. All of these are further elaborated in the following sub chapters.

5.1.1 The excessive use of pesticides

The use of pesticides is the use of substances with the purpose of destroying or limiting pests on the vineyard. They can be used against fungi (fungicides), plants (herbicides), insects (insecticides), bacteria (bactericides) or as a multi-purpose form (IV 13). In the viticulture, the pesticide use amounts to a significant burden on the environment. In fact, a co-author of the vino verde LCA study stated:

''The main problems are related with the application of pesticides. The viticulture stage is more problematic than the wine production stage, for most of the impact categories.'' (IV 2)

This statement was later confirmed by IV1, IV 3, IV4, IV5, IV8, IV9, IV10, IV12, IV13, and was best summarized by one of the top managers of the largest wine company in Portugal:

''Viticulture is intensive in pesticides. The wine industry uses a lot more than we would like to use, even though we are below legally admissible levels in Europe.'' (IV 3)

Multiple studies looking at pesticide use in the agricultural sector and cancer have shown a positive relationship between the two, particularly in children (Bassil *et al*., 2007). One example is the popular herbicide Roundup, which is shown to be highly likely as carcinogenic in a study using rats (Séralini *et al*., 2014). A viticultural manager mentioned the following about this pesticide (Gliphosate is the chemical name for the same substance in Roundup):

''This year about the herbicides. Glifocato appears in all the newspapers because the European Committee wants to forbid the use of this herbicide in Europe. In the Douro this was, of course, a

disaster. We can't survive without herbicides. We are allowed to use it for 10 more years, a herbicide that generates cancer in people.'' (IV 12)

Pesticide use in the agricultural sector has also shown to negatively affect the regional biodiversity of the ecosystem (Beketov *et al*., 2013). A recent study concluded that synthetic pesticides, along with natural contaminants, in the river Douro to be of emerging concern (Rita Ribeiro *et al*., 2016). A study in 2009 measured quantities of 39 commonly used pesticides in the Douro river during spring. In the 84 samples taken, all pesticides were shown to be present and in 60 of them, quantities were above the limits of quantification (João Rocha *et al*., 2011). Among the studied pesticides was the controversial DDT, which has been banned because of its environmental impact and possible carcinogenic characteristics (Beard, 2006; João Rocha *et al*., 2011). The presence of these pesticides in the Douro river show that the effects of excessive pesticide use has concerns to both the regional biodiversity and human health, directly and indirectly. A common belief among pesticide sceptical viticulturists is that these pesticides directly cause human health concerns because of the presence in the wine products (IV 8; IV 9). However, pesticides contaminants in wines are strictly monitored at the IVDP before the products are released on the market (IV 13). But the pesticides do indirectly end up in the river ecosystem, and therefore eventually in the fish which are caught for human consumption (João Rocha *et al*., 2011). The same counts for the ecological effect of the pesticides. On the vineyards they are used to directly eradicate for example insects, of which the local ecosystem is dependent. Mostly birds, like the endangered Douro bird, are severely affected by this, according to the manager of 130 hectares of vineyards in the Upper Douro (IV 6). Indirectly, these pesticides influence the ecosystem of the river due to run-off by rain (João Rocha *et al*., 2011).

Next to human health impact and the loss of biodiversity of the regional ecosystem there are other consequences to the use of pesticides. Specifically herbicides are used to eradicate weeds that are considered harmful and of competition to the vines, the soil is left empty of vegetation, as illustrated in figure 13.

Figure 13. Comparison of herbicide use (left) and no herbicide use (right). Authors' own images.

As a consequence, the exposed soil surface in vineyards using herbicides is eroded to a greater extent than the vineyards that keep the vegetation (Figueiredo *et al*., 1998). To counter this soil erosion, vineyard managers have to invest financial resources on support structures such as walls (IV 3). The exposed soil also has the tendency to contain more dust particles that are more easily caught by the wind, increasing the particulate matter (PM) content of the air in the region, thus negatively affecting the air quality of the region.

5.1.2 Genetic Erosion

The Douro region is historically known for its impressive natural diversity of vines (IV 3). People know the Cabernet-Sauvignon and the Merlot, but far more vine species and sub-species exist. According to one of the founders of PORVID (*Associação Portuguesa para a Diversidade da Videira)*, Portugal has around 250 native varieties (IV 3). Due to mechanization (figure 14) of the wine sector, a lot of these species have been lost (IV 1, IV 3, IV 10, IV 12). The species that were in highest demand by the consumer, or the most suitable for the environment at that time, were used for the entire vineyard. The manager of a large wine company said:

The whole industry is suffering from very strong and very fast genetic erosion. Derived from the fact that nurseries became industrialized 40 years ago and because of their processes, they cannot cope with a large variety of plants to multiply. What is being multiplied, if I am not mistaking, is about 0.4% of the total diversity of the European grape variety. Most of the rest is being discarded and lost (IV 3).

This development creates great sustainability challenges for the future. As the climate is changing, other grape varieties might become more desired for the new environment:

''By studying the diversity of the variety we can then make selections that will maximize traits of interests for the industry. For instance productivity, sugar content, flavour, resilience towards climate change, resistance toward disease, water use efficiency. And that will contribute to the sustainability of the sector.'' (IV 3)

Figure 14. The mechanization of the Douro region resulted in a drastic decrease of grape varieties due to the need for monotype vineyards. Authors' own image.

5.1.3 Water scarcity

The Douro region is characterized by a very hot, very dry summer period and a cold winter with rainfall. During the summer season, there is very little to no rain (figure 16). This is beneficial for the grape production, as the grapes remain small and retain a higher sugar content, as desired by the wine makers (IV 13). However, the hot summers put so much stress on the vines, that irrigation is sometimes necessary to keep the vines alive (IV 1, IV 10). There are two reasons for the increasing need for irrigation on vineyards. On the one hand more and more vineyards are starting business in the Upper Douro, where the climate is the driest, according to a wine company manager and two viticulturist in this part of the region (IV 6, IV 8, IV 9). On the other hand, climate change projections show that the Douro region is suffering upon the effects of climate change; the average temperatures are increasing (figure 15) and the average precipitation is decreasing in the whole region (IV 1). Therefore it can be concluded that the ideal viticultural climate of the Douro region is moving west due to the effects of climate change, but the vineyards are more developing in the eastern direction because of land availability, land prices and the accessibility of the region compared some decades ago (IV 1; Paulo Martins, 2011).

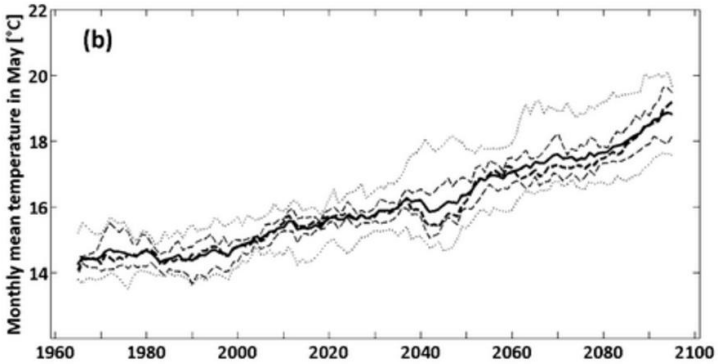

Figure 15. The projected average temperature increase in May in the Douro over the timespan 1965-2095 (Santos *et al.*, 2013).

Figure 16. The Upper Douro is the hottest and driest part of the Douro, illustrated is the dry landscape and the Douro river in August 2016. Authors' own image.

These are the main environmental sustainability challenges that have been found. The next paragraph discusses the economic challenges.

5.2 Economic challenges

When considering the Porto & Douro wine region financial sustainability, it is often stressed that many port wine companies from this region have been commercially active for over 250 years, as discussed in chapter 4 (IV 1, IV 3, IV 8, IV 10). The historical wine trade companies, often of British decent due to historical developments, saturated the market and because of high barriers to entry little to no port wine companies successfully entered the market in a later stage (IV 13, Paulo Martins, 2011). This does not go for the still wine companies from the Douro, as the barriers to entry were and are much lower (IV 13, Paulo Martins, 2011).
However, the Douro wine sector is characterized by significant price competition, which results in low retail prices (IV 10). This comes with great concern for the viticulturists:

''The average price of a bottle for export. Sadly, for port wine, it is not so high. It is crazy but it is below 5 euros per bottle. Imagine, it leaves Portugal at 4,50 per bottle. We are speaking of bottles that have 10, 20 or 30 years long aging. It is crazy and I don't know what happened'' (IV 5).

''We are always thinking the ways to increase the value of our wines, because we believe that our wines are too cheap. Especially in the Douro. If you start seeing all the work that has been done in the vineyard. Quantities are very small, with a lot of manual labour. The prices should be very high.'' (IV 12)

The fact that the quantities are small, is because of the Mediterranean-like climate (Santos *et al.*, 2013). According to an agricultural researcher the productivity of vine in the Douro is between 3 and 5 tonnes per hectare, opposed to 10 to 15 tonnes in wine regions in Germany (IV 1). Next to that the average vineyard size is a lot smaller than other wine regions (IV 11). And the manual labour required makes the costs of producing one kilogram of grape one of the highest in whole of Europe (IV 3, IV 10). The manager of a large wine company sums up this up as follows:

Portugal in terms of international competitiveness cannot withstand other wine regions in terms of productivity and production costs. The only thing that makes us stand out is identity and regionality. (IV 3)

So the combination of a low price of wine, the low production capacity of the vineyards and the high intensity of manual labour characterize the current economic challenges of the Porto and Douro wine region. In the next paragraph the main social sustainability challenges are discussed.

5.3 Social challenges

As described in chapter 4, the Douro region has historically been a poor and underdeveloped region. These days the region is still marked by this discrepancy. Many of the young people move out of the region towards urban areas, such as Lisbon or Porto (IV 8, IV 12). This urbanization trend of young people holds for entire Portugal, resulting in a change in the percentage of rural versus urban population in Portugal (Figure 17).

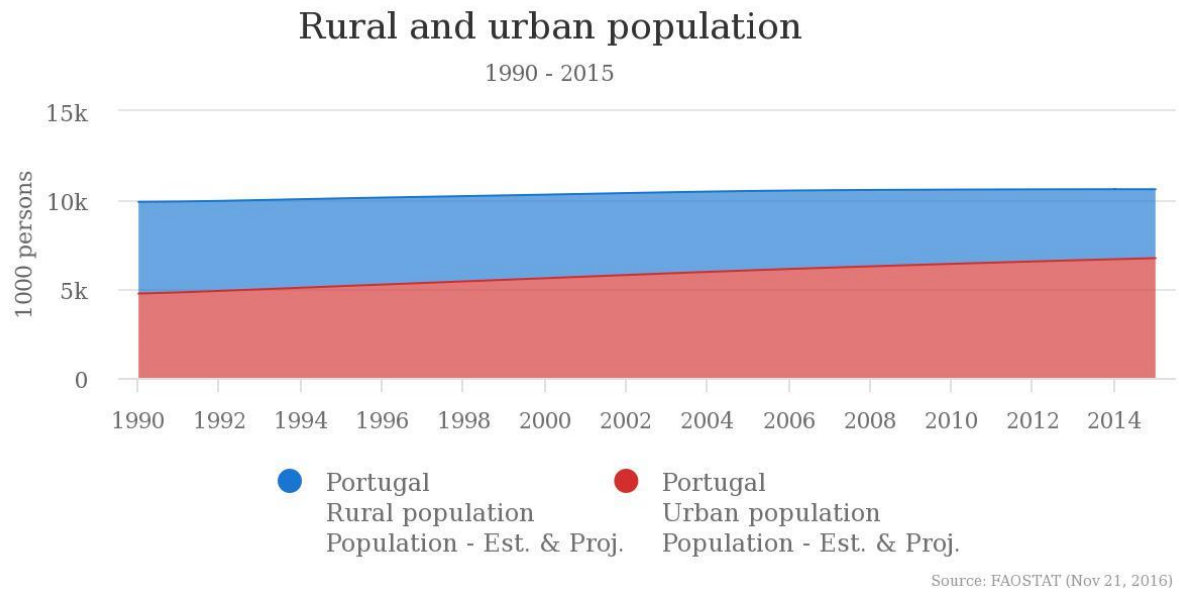

Figure 17. The rural and urban population of Portugal within 1990 until 2015 (FAOSTAT, 2016).

What the people are experiencing regarding this exodus in the Douro region is described by a viticulturist from the Upper Douro:

''Here there is nothing, you are far from everything so people don't want to come here to live. (…) It's one of the big problems that people don't want to live here. (…) it is difficult to live here because you are in the middle of nowhere. Most of the producers like me live in the bigger towns like Vila Real or Porto.'' (IV 8)

Hence, the population in the Douro region is declining in recent years. This is a concern for the viticulture in this region, as best summarized by a top manager of a big wine company:

''Another very important issue in the Douro is labour. It is a population scarce region, because of the geomorphology of the region mechanization is not complete (we cannot mechanize everything there). This is because of the slopes and because it is very rocky and very unstable for machines. We use a lot of labour and this is not bound to be reduced. Labour is an issue, having good social conditions, not just wages but also social conditions for people to live there and stay there is very important.'' (IV 3)

The high dependency of the Porto and Douro wine region on manual labour in the Douro valley and the current trend of urbanization characterize the social challenges of the region. The next chapter elaborates on the regional wine innovation system, as presented in figure 4.

6. Results: Regional Innovation system of the Porto & Douro wine sector

In the following chapter the RSIS of the Porto and Douro wine region is presented (figure 4). First, all the actors are presented in figure 18. Then, they are discussed according to the three categories of actors from the research domains (chapter 6.1), governance domain (chapter 6.2) and the business domains (chapter 6.3) respectively. Lastly, the culture and institutional framework of the Porto and Douro wine sector are discussed (chapter 6.4 and 6.5).

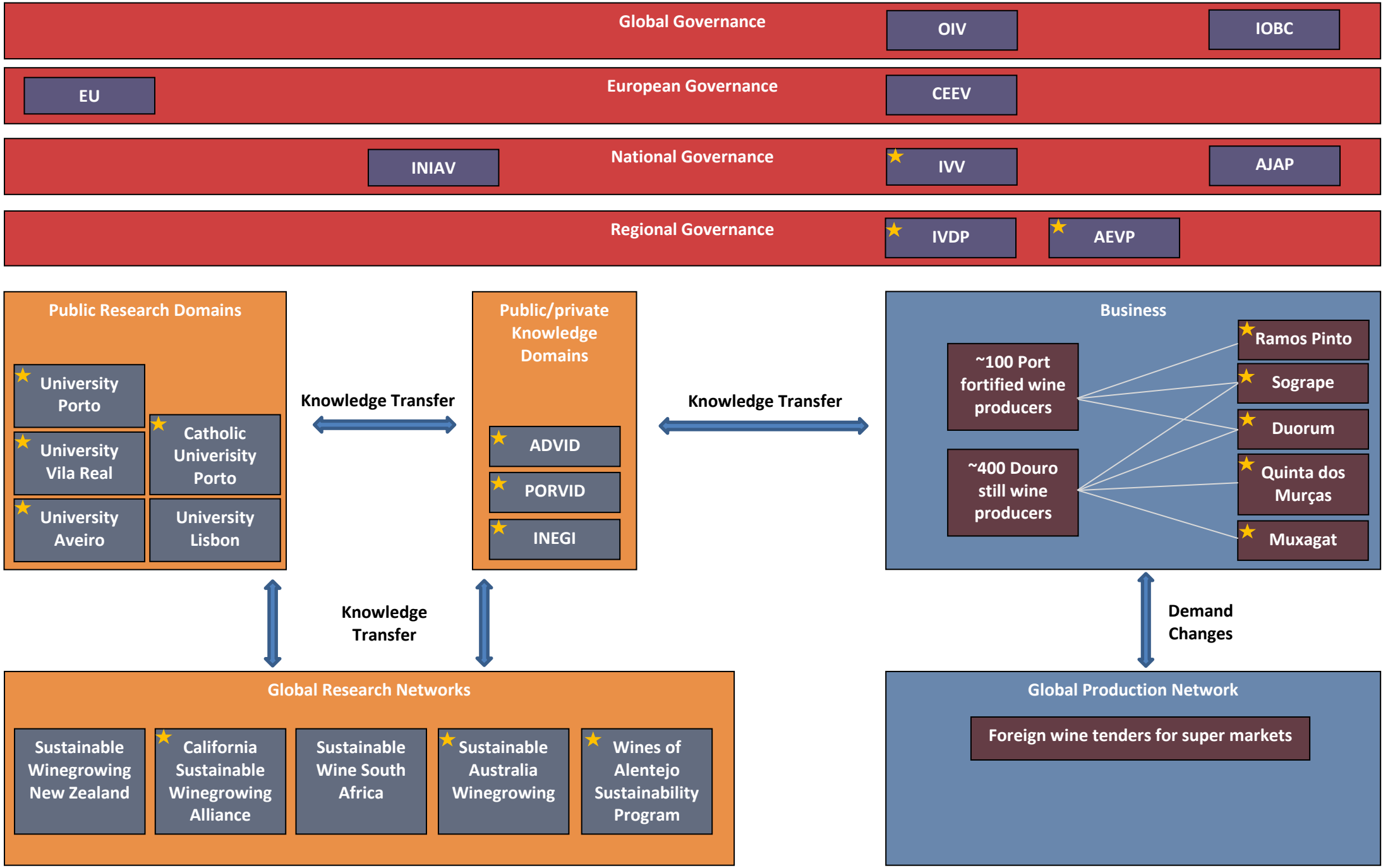

***Figure 18**. The regional wine innovation system in the Porto & Douro region,*
★All actors presented with a yellow star have been interviewed in this research.

6.1 Knowledge domains

As can be seen in figure 18, the knowledge domains within the regional wine innovation system of Porto & Douro are represented in three different orange coloured boxes, global research networks, public research domains and public/private knowledge domains.

6.1.1 Global research networks

The global research networks regarding sustainable wine production can consist of a very large amount of actors, but those identified by the interviewees are discussed. These are the voluntary sustainability winegrowing programmes in New Zealand, California, South Africa, Australia and Alentejo. The latter is a different wine region in the south-east of Portugal that very recently started to implement their own sustainability program, inspired by the California Sustainable Winegrowing Alliance, as confirmed by the sustainability manager of Wines of Alentejo Sustainability Programme (WASP) (IV 7, IV 11):

''So we had a president before the current one, she lived in California and she knew what they were doing in California. She pretty much proposed to Alentejo to have something similar as they were doing'' (IV 11).

6.1.2 Public research domains

The public research domains are the national research domains that influence the wine sector, according to the interviewees (IV 1; IV 2; IV 3; IV 4; IV 5; IV 10; IV 11; IV 12; IV 13; IV 15). The following universities have been identified: The Universities of Porto, Aveiro, Vila Real, Lisbon and the Catholic University of Porto. Within the universities, some faculties (such as the faculty of engineering of the university of Porto) were more connected to the wine sector than other faculties, but for simplicity the whole university has been considered.

6.1.3 Public/private knowledge domains

Three actors are identified in the public/private knowledge domains, being partly or fully financed by the industry (IV 5).

ADVID, Associação para o Desenvolvimento da Viticultura Duriense, acts as a research institute for the wine sector in the Douro. It is situated in Peso da Régua, in the Lower Corgo, and has a primary research focus on biological hazards for the viticulture i.e. pest control (IV 12).

PORVID stands for Associação Portuguesa para a Diversidade da Videira. It was identified that the Porto & Douro wine sector experienced a significant loss in vine biodiversity (IV 3). To save these genotypes from being discarded, the wine industry identified the need for an institute for the protection of vine biodiversity, which has been realized in 2006, PORVID was born (IV 3). Both ADVID and PORVID are financed by the industry (IV 3; IV 10).

INEGI is a bit different, this is the Institute of Science and Innovation in Mechanica land Industrial Engineering. This institute is half financed by industries and half by the University of Porto (IV 5). In the past a research team of INEGI collaborated with ADVID to tackle mechanization challenges that the Douro region is facing (IV 4; IV 5).

In the next paragraph, the governance domains are elaborated.

6.2 Governance

On a governance level the Porto & Douro wine sector includes governmental entities and organizations, on many different levels of operation. A clear distinction can be made between Global, European, National and Regional governing entities, which are further elaborated below.

6.2.1 Global

During the interviews, the OIV (*The international Organisation of Vine and Wine)* was mentioned as an important source for sustainable wine production knowledge, according to the coordinator of the knowledge institute of the IVDP (IV 15). The OIV is an intergovernmental organisation of a scientific and technical nature of recognised competence for its works concerning vines, wine, wine-based beverages, table grapes, raisins and other vine-based products (OIV, 2016; IV 3).
The IOBC (*The International Organisation for Biological and Integrated Control*) promotes; 'environmentally safe methods of pest and disease control. It is a voluntary organisation of biological-control workers' (IOBC 2016).

6.2.2 European

On European level the entity CEEV (*Comité Européen des Entreprinses Vins*) is the representative professional body of the EU industry and trade in wines (CEEV, 2016). The CEEV has four objectives on sustainable wine production; 1) improving environmental performance, 2) overcoming uncoordinated proliferation of environmental standards, 3) supporting EU methodologies, and 4) promoting the improvement of the energy and environmental performance of wine production (CEEV, 2016). It represents 90% of the EU wine export, which is a total of more than 8 billion euro (CEEV, 2016).
The European Union also has agricultural policies in which, for example, maximum exposures to pesticides are included. These legal limits also exist for vine and wine, thus the European Union can influence the regional wine sector significantly (IV 13).

6.2.3 National

IVV *(Instituto da Vinha e do Vinho*) is a national institute that governs the institutional organization of the wine sector in Portugal, and it monitors EU policies and prepares these for implementation in the wine sector (IVV, 2016; IV 13).
INIAV (*Instituto Nacional de Investigação Agrária e Veterinária*) is the state research centre for agriculture, forestry and rural development. They develop research activities in the agronomic and veterinary fields (INIAV, 2016; IV 3).
AJAP (*Associação dos Jovens Agricultores de Portugal*) is a farmers' organization that aims to introduce change and innovation to farms and agricultural enterprises. They defend the young farmer interests and take care for their representation, partially by organizing a yearly conference (AJAP, 2016; IV 3).

6.2.4 Regional

IVDP (*Instituto dos Vinhos do Douro e Porto*) **"**The mission of IVDP, is to promote the control of the quality and quantity of Port wines, regulating the production process, and the defence and protection of the Douro and Port denominations of origin and the geographical indication of the Douro Region.'' (IVDP, 2016). The wines and vineyards in the Douro region are directly controlled and governed by the IVDP. This institute is financially self-supporting. All wine producers have to pay a small fee to have their wines certified. The IVDP is directed by the IVV, and these two work closely together. Employees working at IVV can be found daily in the IVDP office (IV 13; IV 15).
The main purpose of AEVP (*Associação das Empresas de Vinho do Porto)*, enshrined statutorily, is to ''represent and protect the interests of its Members and to promote and defend of Industry and Trade of Port and Douro wines and other wine products of the Douro Demarcated Region (AEVP, 2016).
In the next paragraph, the business domain is elaborated.

6.3 Business domain

The Douro region is represented by about 100 unique fortified Port wine producers and 400 'Douro wines', or still wine producers (IV 10), as has been described in chapter 4.2. Compared to other wine regions in Portugal and abroad, this is a high number of producers, each company representing a relatively small viticulture area in the Douro region (IV 11). However, many of these individual companies are part of holdings. Sogrape and Symington are the largest holdings, each owning over a dozen companies (IV 8). A viticulturist stated:

''There are like 5 groups, Sogrape, Symington etc. When you have a region that is ruled by 5, you are going to have problems. They can change the rules.'' (IV 8).

This clustering of companies has also been discussed in chapter 4.1. As the barriers to entry are high, almost no port wine company is successfully introduced in the market recently. But in times when the port trade was suffering, like during World War Two, the larger companies were able to expand their market share by buying smaller companies (Paulo Martins, 2011).

Internationally, most wine products from the Porto & Douro region are exported, namely to supermarkets through retailers (IV 3; IV 10).

6.4 Culture

The culture of the Porto and Douro wine region is inherently connected to the history of the region. As chapter 4.1 showed, it has always been a poor and underdeveloped region which suffered a lot from every economic and biological crisis in the past 250 years. The mentality regarding changing production practices of the farmers is described very frequently in the interviews, most of the interviewees identified a resistance to change (IV 1; IV 3; IV 4; IV 8; IV 9; IV 10; IV 11; IV 12; IV 13). An agricultural researcher described it as:

''There is not necessarily a fear, but things are done in a certain way for a lot of years. There is certainty in no change. There are some drawbacks to change. We have to be prepared to change and to offer different adaptation measures if it is needed.'' (IV 1).

A viticultural manager mentioned:

''It's impossible to forget that we are in the oldest demarcated wine region in the world. It's also impossible to forget that it's a region with 270 years of tradition, things that people who think that it's the right way to do it. And well, it's a cultural issue. It belongs to the terroir I believe.'' (IV 12).

This view that the mind-set of the people working the wine sector is resistant to change is illustrated by a viticultural manager that applies cover crops in his vineyards (cover crops are weeds, such as grass species, that retain the soil between the rows of vines). He mentioned to receive phone calls from neighbours and people passing by, judging him for his irresponsible practices on the vineyard (IV 12). According to the technical director at the IVDP, this mind-set of farmers is the biggest challenge that the wine region faces (IV 10).

6.5 Institutional framework

The institutional framework in which the Porto and Douro region operates are the applied laws and standards regarding sustainable wine production. According to the technical director of the IVDP there are currently no institutional reinforcements for sustainable wine production practices at this moment, but there is the ambition to have them in the future (IV 10). There is also no sustainability related legislation for vine growers (IV 10). What does exist are legal limits to the use of pesticides, directed by the EU (IV 12). The EU is getting more strict about pesticide use, and regularly the limitations are becoming more strict (IV 4, IV 5; IV 12).

There are also global guidelines and initiatives to stimulate sustainable wine production on a voluntary basis. These are mostly based on the pesticide use in the viticulture. One that is used is the Integrated Pest Management (IPM) (IV 3). It is a European Union directive that provides guidelines for agricultural practices, including pest management (IOBC, 2016). IPM does not abolish the use of pesticides, rather it is a continuous evolving list of pesticides that have been found to be the 'best choice' (IV 3). So when a new pesticide comes on the market with a lower impact on human health or the environment, the old pesticide becomes prohibited. Next to the approach of using the least harming option, they also use the concept of 'economic level of attack' (IV 3). According to IPM, by taking a number of samples the farmer can measure it's economic loss of using no treatment and by using a pesticide treatment. The pesticide treatment has a certain cost, and if this does not outweigh projected affected grapes due to pests as determined from the picked grapes from the vineyard, the treatment does not make economic sense (IV 3; ENRD, 2014; Ehi-Eromosele *et al*., 2013). IPM has its origin in the seventies of the last century (Ehi-Eromosele *et al*., 2013). A natural evolution of this is the Integrated Production of grapes directive which was developed in Switzerland and is being certified since 2003 (IV 3; Viret, 2013). The IOBC published the guidelines in 1996, a second edition in 1999 and the most recent version, third edition, in 2007 (Malavolta & Boller, 2007), making it available globally. Integrated Production of grapes includes guidelines to retain biodiversity, reduce pesticide use, minimize pollution and protect the farmers' health (Malavolta & Boller, 2007). At this moment, about 15.000 hectares (33%) of vineyard are certified under Integrated Production of grapes in the Douro region (IV 3), with the largest share in the hands of the bigger producers (IV 3).

Another alternative is the implementation of organic wine production. The Standing Committee on Organic Farming (SCOF) is a committee that determines the EU policy regarding organic farming, including organic wine. The rules for organic wine have been changed in 2012, which are essential to comply to in order to use the EU organic logo (EU 203, 2012). In its essence, organic wine production is a strict set of rules regarding oenological practices that include few controlled (natural) substances (EU 203, 2012).

One other set of laws that are applicable to the Douro region are related to the UNESCO classification (IV 5). As the terraces of the vineyards in this region are a unique landscape characteristic, they have been protected by UNESCO in 2001 (UNESCO, 2016). In the next chapter, the RSIS and sustainability challenges are analysed.

Biodynamic viticulture

During the empirical research, a unique movement was identified that has a different view on viticultural practices, such as pesticide use. The movement of *biodynamic* farming was developed in the early 1920s based on the work of philosopher Rudolf Steiner and can be seen as a unique type of organic viticulture (Villanueva-Rey *et al*., 2014). The agricultural methods are derived from a spiritual philosophy and are guided by, among others, seasonal and planetary cycles (Delmas, 2010; Rolandi & Saba, 2015). Nonetheless, within *biodynamic* viticulture, an independence of mineral fertilisers and synthetic pesticides is required, and the wines are certified under stricter conditions than the EU organic wine regulation (Villanueva-Rey *et al.,* 2014; Rolandi & Saba, 2015). The practices of *biodynamic* do include elements such as plant diversity, crop rotation and composting, which are important aspects of sustainable wine production (Delmas, 2010). Within this study *biodynamic* viticulture is considered as a form of organic viticulture, since some of the additional practices have a spiritual foundation that is questioned in on its scientific legitimacy (Rolandi & Saba, 2015).

7. Analysis

This chapter analyses the factors that are supporting or hindering the development of sustainable wine production, based on the results of chapter 5 and chapter 6. The main sustainability challenges, as discovered in chapter 5 are analyzed in part 7.1 (environmental challenges), 7.2 (economical challenges) and 7.3 (social challenges). In part 7.4 the knowledge transfer and in part 7.5 the changes in demand are discussed, as they are the variables of the RSIS, which is shown in figure 18. In part 7.6 factors from the legislative framework are discussed, as these have been found to be of importance to sustainable wine production development. A summarizing figure is presented in part 7.7.

7.1 RSIS and Environmental challenges

Chapter 5.1 elaborated on the findings that 1) the vineyards in the Douro apply too many pesticides on the vines, 2) the vine biodiversity is threatened (genetic erosion) and 3) the water use is critical (water scarcity). The following subchapters discuss the influencing factors from a RSIS perspective on these sustainability challenges.

7.1.1 Analysis: excessive pesticide use

There are a couple alternatives for vine growers when it comes to using pesticides compared to 'business as usual' i.e. excessive pesticide use. As described in chapter 6.5, a few frameworks support dealing with pesticide use, such as the 'organic wine growing' from the EU (EU 203, 2012). This form of wine production is a big topic of discussion in the Douro region according to a viticultural manager (IV 12). A few vineyards have adopted this organic approach, mostly in the Upper Douro, but managers from traditional vineyards are very sceptical on the financial feasibility and on the quality of the wines of these organic vineyards (IV 3; IV 8; IV 9; IV 12). There is a reason for this concern; a viticultural manger with 5 hectares of organic vineyards mentioned that at the moment operations are changed to organic the production of the vineyard is reduced by 20% (IV 12). Grape production is traditionally maximized by use of fertilizers and pesticides, by removing this the production capacity returns to the natural balance. **The financial risk of losing production capacity** involved is therefore hindering sustainable wine production.

By using less or no pesticides and in particular herbicides, the vineyards get vegetation growing in between the vines, as illustrated in figure 15. This vegetation is a concern for viticultural managers, as the general belief is that this vegetation, also known as cover crops, competes with the vines for nutrients and water (IV 1; IV 8; IV 12). However, according to an agricultural researcher of the University of Vila Real, the vegetation does not compete with the vines when the vine needs it most (IV 1). The vegetation will thrive when there is a lot of rain, reducing soil erosion in winter and spring, but the vegetation is dried out before the vines get in water stress during the hot summer months (IV 1). The viticulturists appreciate the visual appearance of vineyards without any additional vegetation (IV 1), and this **pesticide use mentality** is, in this case, hindering sustainable wine production.

This is a mentality that we need to change, people don't like cover crops. They like their fields completely clean with only vines. (IV 1)

The amount of pesticides required to meet the desired effect is very dependent on weather conditions when applying the pesticides (Viret, 2013; IV 1; IV 12). If there is wind or rain, the effect of the pesticides is reduced. Due to wind the pesticide mixture can be misdirected and evaporated, and rain flushes the pesticides off the vines (IV 4). Weather projections rely on accurate measuring of weather data by measuring stations (figure 21) (IV 4; IV 5). Students from the University of Porto created a start-up, called 'Wisecrop', that provides viticultural managers with accurate weather projections and included calculations on the best times to apply pesticides (Wisecrop, 2016; IV 5).

This start-up is currently situated in Porto, it provides the tools required to reduce the pesticide use (Wisecrop, 2016). **Entrepreneurship**, especially regarding meteorological applications, is therefore a factor that is, in this case, supporting sustainable wine production.

Figure 19. Meteorological instruments in the Douro region that are used for weather forecast, which is required to find the best times to apply pesticides on the vineyards to reduce the overall pesticide use. Also illustrated on this image are vertical plantations on the foreground and horizontal plantations on the other side of the river, on the background. Authors' own image.

7.1.2 Analysis: genetic erosion

The Porto & Douro wine sector is suffering a very fast genetic erosion (IV 3). It has been elaborated in chapter 5.1.2, that the main cause of this genetic erosion is the mechanization of the vineyards. The mechanization was made possible when vineyards were transformed from horizontal plantation to vertical plantations, allowing easier access for machines (figure 21) (IV 12; IV 13). The first plantation to be planted vertically was at Quinta dos Murças in 1947 (IV 12). These mechanized vineyards were the first to be planted with monocultures, hence the overall biodiversity of the vines in the region decreased (IV 12). As a response, an institute was founded in 2006, called PORVID (*Associação Portuguesa para a Diversidade da Videira).* It is responsible for collecting and safeguarding the natural biodiversity of vines, and according to one of the representatives it now has around 210 out of 250 native species, and about 30.000 out of 50.000 genotypes (IV 3). In response to this challenge, the larger wine companies including the largest 'Sogrape', together with University of Lisbon and University of Vila Real, and the ministery of agriculture of Portugal (INIAV) created the institute. Therefore, this challenge has been addressed with a solution in 2006, **the general acknowledgement of the issue of genetic erosion** and the consensus that a solution was required supported a sustainable solution in this case.

7.1.3 Analysis: water scarcity

It is clear that the Douro region is a very water scarce region, especially during the summer months, as elaborated in chapter 4.2.1 and 5.1.3. A top manager from the largest Portuguese wine company mentioned:

Water is one of the main issues there (in the Douro). Because it's a water scarce region and we have to achieve our production without using a lot of water, ideally using none. We are coming to a moment where using none is getting very hard. So what we have to do is to rethink all our processes in terms of decreasing our water footprint as much as we can. Especially the grey water footprint. It is the water you need to treat the residues from the processes. (IV 3).

Currently, irrigation of the vineyard is only allowed by law if the yard is in a lot of stress (IV 1; IV 10). Still, some vineyards are currently endangered as not all vineyards are equipped with irrigation systems. The use of irrigation systems is controlled and has to be approved by the governance domain, IVDP, before it is allowed (IV 13). It has been mentioned that water pumping from the Douro river happens illegally, in order to prevent strict control by the IVDP and to reduce the hassle (personal communication, IVDP). In this case, the **strict legislation regarding irrigation** is hindering more sustainable wine production. Smarter irrigation systems have been developed in Australia in recent years, such as drop-by-drop irrigation and partial root irrigation (so the vine receives the necessary water on one side and retains the drought response on the other) (IV 1). The standard electrical pumps also have a large energy consumption (IV 5). The strict legislation leaves little space for such irrigation systems to be implemented and/or improved.

The manager of a large wine company also mentioned the 'grey water footprint' (IV 3). This is the water used for treatments such as cleaning machines required for winemaking and storage tanks (IV 3). There is concern about the current regulation that applies to this water (IV 9; IV 10; IV 12). As the water is used for cleaning purposes, it has to be treated as wastewater i.e. transported to a wastewater plant. In the past this water was used as a compost on the land for the fruits and vegetables, as quinta's were self-supporting micro communities which had viticulture on the side (IV 8; IV 9). Currently there are techniques available in France where this wastewater is combined and made into a compost and returned to the vineyards (IV 9). Also a viticultural manager is trying to reutilize the grey water to directly compost and irrigate the vineyards (IV 12);

In terms of water, we are trying to reutilize the water from our residual water. To reuse it. It's a big achievement, all the people get water down in the river and we try to reuse that water. (IV 12)

However, this idea meets resistance in the current regulations (IV 10; IV 12). The **strict regulations regarding grey water use** are, in this case, hindering sustainable wine production. Opportunities are identified to make better use of the grey waters that come from the wine production, such as using it for irrigation and/or for compost.

7.2 RSIS and Economic challenges

In chapter 5.2 it has been elaborated that the Porto & Douro wine region has financial challenges. It is the wine region with one of the highest costs for wine production, due to the costs of manual labour, as it is not completely mechanized (IV 3). The retail price of the wines are, on the other hand, relatively cheap. Too cheap even, according to three viticulturists (IV 8; IV 9; IV 12). The **current price of the wines** is a hindering factor to sustainable wine production, because any investment that would increase the sustainability of the regional wine sector is considered twice (IV 3). Added costs that could increase the environmental sustainability are a concern for the economic sustainability.

Because of the above mentioned financial restrictions it becomes clear that investments based on long-term sustainability goals are more dependent on funds from the Portuguese government or the European Union. The Portuguese government however, currently operates with finance conservation as a high priority, as the European Union set limits on the governments expenditure to get the balance back in order (IV 10; IV 13). Therefore, **external funds opportunities** from Horizon2020s and other European Union programmes are key to the sustainable development of the Porto & Douro wine region (IV 4; IV 5; IV 11).

7.3 RSIS and Social challenges

As discussed in chapter 4 and chapter 5.3, the Douro region has always been a poor and underdeveloped region. The population in the Douro region is declining in recent years. This is a concern for the viticulture in this region, as it depends on the population for manual labour (IV 3). In order for this trend to stabilize and potentially reverse, governmental actions are required to increase connectivity and/or create incentives for people to live and stay in the Douro region (IV 8). However, some developments are taking place that can improve the conditions for living in the Douro region. Different types of tourism, mostly ecotourism and wine tourism, are increasing in the region for the past few years (Feio & Correia Guedes, 2013; Rebelo *et al*., 2015; IV 1). Along with this tourism come economic opportunities. An example of ecotourism in the Douro region is illustrated in figure 20.

Figure 20. An ecotourism location in the Upper Douro, authors' own image.

Both ecotourism and wine tourism in the Douro region are connected to the viticulture of the region. Viticulturists use this possibility to create an additional income by creating accommodations (IV 8). This **increase in tourism** is therefore supporting sustainable wine production in the Douro region, as it creates economic opportunities for people living in the Douro region, limiting the outflow of people to urban areas.

Another crucial part of the social challenge is the identified issue of the mind-set of farmers regarding pesticides (chapter 6.4). In light of the previously discussed pesticide use, an agricultural researcher stated the following:

''The growers here apply those products (pesticides) every year, even if in that particular it is not required to be applied. It is rooted in the tradition of the Douro valley so people tend to do what the farmer next to them does. It's all about what the neighbour does.'' (IV 1)

The mind-set challenge is not only identified at the viticultural stage, but also at the wine production and distribution stage (IV 10; IV 11; IV 12). A sustainability manager mentioned the following about the management of the largest wine company in the region and the bottle in which the product is distributed:

''Yet, with all the efforts, and with all the knowledge IV 3 has, he has huge problems convincing the management of Sogrape. Which, bear in mind, is the biggest wine company in Portugal, one of the biggest in the world. Those guys have money (…), they can do whatever they want. If they want to, they can do whatever they want. Yet, the mind-set is not there yet.'' (IV 11)

''They never want to talk about the bottle. It's sacred. But I just ask them. So I ask 'why won't you take 200 grams of the bottle nobody will notice, who cares'. And you multiply 200 grams by a million, and you see how many kilos of glass you save?'' (IV 11)

It is clear that the business segments' mind-set in the of overall **resistance to change** is one of the main hindering factors of sustainable wine production in the Porto & Douro region. In the next part, the knowledge transfer within the RSIS is discussed, being an important variable in theory (chapter 2) and empirically, that connects the knowledge, governance and business domains.

7.4 Analysis: knowledge transfer

The conceptual framework includes the knowledge transfer between research organizations and the business domain. Ideally the knowledge from the global research networks, the public research domains and the public/private knowledge on sustainable wine growing trickles down through the RSIS to the farmers. In this step a loss of knowledge transfer potential is observed, as both the research institutes PORVID and ADVID work with associates, i.e. cooperating organizations (IV 3). PORVID has 19 associates with only the largest wine companies involved (IV 3). ADVID has a wider audience with 160 associates, representing 15.000 hectares of vine in the Douro region (45.600 hectares are covered in vine in the region) (IV 3). An interesting observation is that one of the largest wine houses in the Porto and Douro region, Taylors, is not an associate of ADVID, therefore hindering the successful spread of their sustainable wine growing knowledge to smaller wine growers. This is especially alarming because the smaller winegrowers that control the largest share of viticultural area cumulatively (IV 1). The information from ADVID is freely available for them, but as they are a smaller operation, they don't have the time or lack other necessary skills to invest time in this according to a retailer and a researcher:

''The bigger companies have easier access to the information while small growers don't tend to look at the freely available information.'' (IV 1; IV 3)

Hence, **the lack of coverage among the winegrowers of the regional wine research institutes** is a hindering factor to sustainable wine production.

Next to the lack of coverage by these regional research institutes, the general lack of information sharing is also identified as a hindering factor for sustainable wine production (IV 12; IV 13). A viticulturist explained:

''Mentality again. Last year or 2 years ago, with the science university, they started a European programme to evaluate the footprint of the production I believe. And it stopped. Because, no one wanted to say the exact quantity of wine it produced, the quantity of electricity used, the quantity of water used. It's always like ''more or less like this'', ''more or less like that'', ''could you send us the consumption of the natural gas?'', ''no sorry we don't have it''. (IV 12)

The Portuguese wine sector is not transparent (IV 10). Initiatives in which producers can compare their own water use and electricity use to, for example, the neighbours are not possible (IV 10). Such initiatives are known to initiate sustainability efforts according to two sustainability managers (IV 7; IV 11). Therefore, the **lack of transparency** in the sector is hindering sustainable wine production in the Porto & Douro wine region. The next part discusses the changes in demand, which are present between regional and global wine business domains.

7.5 Analysis: changes in demand

The conceptual framework includes demand as an important variable for transactions between the global wine market and the regional wine businesses. Observed is that especially in the northern export countries such as Sweden, Germany and Canada, an increasing amount of supermarket tenders exist for sustainable wines. A change in demand therefore does exist, creating a **growing sustainable wine market** which is a factor that is supporting sustainable wine production (IV 3; IV 7).

A change in demand is also detected in younger generations. The so-called 'Millennials' generation have higher demands on products they buy, as they want to know about the origin and the characteristics of the wine (IV 12) A viticultural manager described it as:

''Now millennials, even in the United States, or in Nordic countries, they want to know everything. When they buy a bottle of wine they want to know everything. And even the carbon footprint from the wine until there.'' (IV 12)

This change in demand from the consumer seems likely to be connected to the rise in sustainable wine tenders of supermarkets. After all, the supermarkets have the ambition to connect their products to the consumer demand. Nonetheless, the **increased interest from younger consumers in sustainability aspects** of the wine products is a factor that is supporting sustainable wine production. The next part discusses factors found in the legislative framework of the RSIS.

7.6 Analysis: legislative framework

The institutional framework of the RSIS has been described in chapter 6.5. One factor that has been identified is the strict legislative framework of specifically port wine production (IV 8). A port wine viticulturist mentioned:

''There is a big discussion about port, it is a very complicated area. Port wine is ruled by very protectionists rules that don't let innovation and new projects in.'' (IV 9)

These rules have existed for over seventy years (IV 8). They were considered necessary as port wine was a large export product of great importance to the economy of Portugal. Nowadays the Portuguese economy depends far less on port wine, as it only has a marginal share of the total exports (IV 8).

Most sustainability developments in the Porto & Douro region now are happening in the still wines, rather than the port wines (IV 8; IV 9; IV 12). The **strict legislative framework on port wine** is therefore hindering the sustainable wine production of the Porto & Douro wine region.

7.7 Summary

The following figure presents the conceptual model with the found hindering and supporting factors to sustainable wine production. The factors have been numbered and illustrated where they are connected in the RSIS.

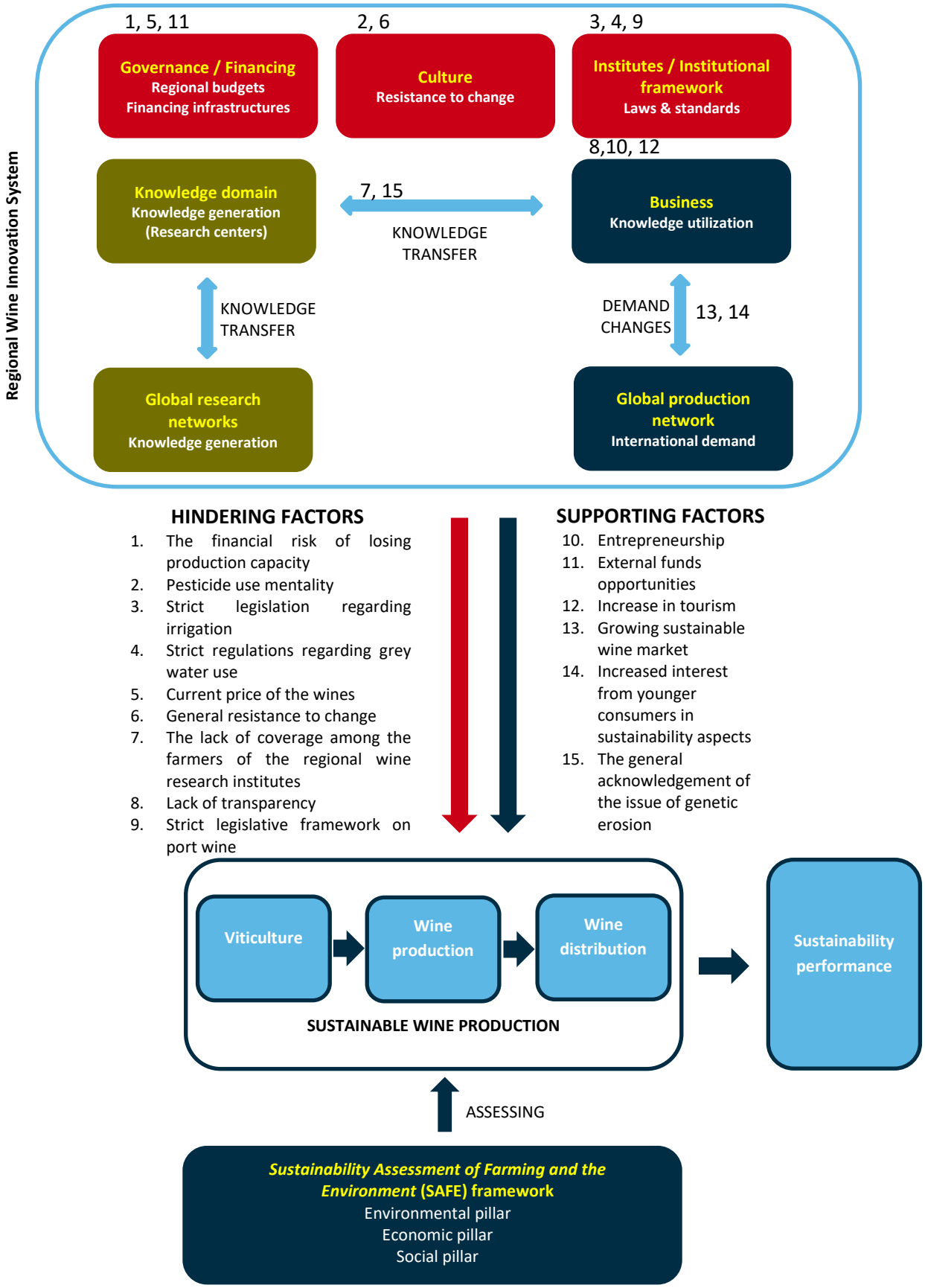

Figure 21. The conceptual framework with the found supporting and hindering factors.

8. Comparison with the New World wine region

Together with New Zealand, Australia and South Africa, California is identified as a front-runner region in the field of sustainable wine production. This is largely due to the existence of a sustainability organization for the local wine sector as elaborated in chapter 3. This chapter, first gives a brief overview of the front-runner region California regarding sustainable wine production (part 8.1). Then in part 8.2 the cases are compared to explore possible lessons and discrepancies with the Porto & Douro region. In part 8.3 the New World wine region comparison will be concluded.

8.1 California Sustainable Winegrowing Alliance

A characteristic of this New World wine region is the presence of a sustainability organization specifically for sustainable wine production (IV 3; IV 7; IV 11; IV 15). Other front-runner regions also have a similar organization: in New Zealand, it's the Sustainable Winegrowing New Zealand (SWNZ), in South Africa it's the Sustainable Wine South Africa (SWSA) and in Australia it's the Sustainable Australia Winegrowing (SAW). In California it's the CSWA; California Sustainable Winegrowing Alliance.

The CSWA is *''a San Francisco-based non-profit organization incorporated in 2003 created by Wine Institute and the California Association of Winegrape Growers to promote the benefits of sustainable winegrowing practices, enlist industry commitment and assist in implementation of the Sustainable Winegrowing Program''* (CSWA, 2016).

According to the CSWA program manager, all the programmes are very similar, covering very similar topics such as soil, water, biodiversity, energy, pesticides, and pesticides (IV 7; IV 11). The first steps to founding the CSWA organization were made in the year 2000 (IV 7). At that moment there were already some regional programmes, and the need to bring this state-wide was identified by the two major associations of the California wine sector (IV 7). These were the Wine Institute and the California Association of Winegrape Growers (CAWG) (IV 7). The goal of the newly founded CSWA was to drive sustainability and improvements in the industry (IV 7). The first project was the writing of the California Code of Sustainable Winegrowing Workbook which is an educational book and a self-assessment tool (IV 7). The program manager of the CSWA explained about the first time grape growers were participating in the workshops:

''It was great to get people understand what sustainability even is about. Also to see that they are already doing these practices and that it's not something crazy new that people would be forcing them to implement. That was an important step: the understanding what sustainability means and doing so many of the practices, but also definitely getting improvements.'' (IV 7).

In 2010, the CSWA launched their sustainable winegrowing certification program as an add-on to the sustainable winegrowing self-assessment tool, after three years of finding consensus between the grape growers and the wine producers (IV 7). Many of the sustainability programmes for wine have started off as a self-assessment or as an educational programme. Recently newer sustainable wine programmes such as in Chile and Italy, immediately start of as certification programmes (IV 7; IV 11). According to the sustainability manager of the Wines of Alentejo Sustainability Programme (WASP), this is because the market demand for sustainability labels for wine is growing (IV 7; IV 11).

8.2 The RSIS differences between the Old World and New World wine region

A certified wine educator from Napa valley, California, stated about his wine sector in an online tutorial:

''*The wine sector is not a transparent industry*'' (Tim Hanni, 2014).

This characteristic is found to be true for the Porto & Douro region too. In this sub-chapter, the differences between the case-study region (Porto & Douro wine region) and the California wine region are elaborated. Several differences are identified, such as the lack of a representative organization for the grape growers (8.2.1), 2), the collaboration between wine producers and grape growers (8.2.2), different history (8.2.3) and the financial means (8.2.4).

8.2.1 The lack of a representative organization for the grape growers in Porto and Douro

This CSWA organization was founded by the Wine Institute, which is the IVDP in the case-study region (IVV on national level in the case-study region), and the CAWG, of which no direct equivalent exists in the Porto and Douro wine region. **The farmers in the Porto & Douro region are not adequately represented** (IV 3). A top manager of the largest wine company in the Porto and Douro region stated the following:

''The representativeness of the growers (in the Douro) is not what it should be. So this is a weakness of the system.'' (IV 3).

In the Porto & Douro wine region, the AJAP (*Associação de Jovens Agricultores de Portugal)* institute is the closest equivalent to the CAWG (*California Association of Winegrape Growers)*. However, AJAP encompasses the entire agricultural sector in Portugal and has no specific focus on the wine sector (AJAP, 2016). In the mission statement, AJAP mentions it operates with limiting financial resources (AJAP, 2016). Hence, it is very challenging to achieve the similar sustainable wine production results in the Porto & Douro region, compared to California.

8.2.2 Collaboration between wine producers and grape growers

In California, before the CSWA, the grape growers and wine producers did work together if there was, for instance, a public issue, but other than that there was little cooperation between the two (IV 7). It is described by the program manager of the CSWA that after implementation of the CSWA, both the grape growers and the wine producers started working together on tackling sustainability issues a lot more (IV 7):

''So it was interesting that the sustainability piece was really pushed by the two heads (presidents) of the associations, as a way that there is a way that we can come together and work together as the industry. And it has worked. In general, the sustainability initiative within the California wine industry has brought growers and wineries together. Talk more about common interests, not like 'you are the grower, I am the buyer'' (IV 7).

Both the program manager of the CSWA (California) and the sustainability manager of the WASP (Portugal) stress on the importance that the **dialogue between the grape growers and the wine producers**, and with it the necessary **information sharing**, are essential to achieve more sustainable wine production (IV 7; IV 11).

8.2.3 Different history between the New World and the Old World

One significant difference is the role of history in California compared to the Porto & Douro wine region (IV 1; IV 10; IV 11; IV 15). In fact, history is the primary difference between the 'Old World' and the 'New World'. For example, as discussed in chapter 5.1.2, genetic erosion of the vines is identified as one of the environmental sustainability challenges of the Portuguese Douro region. In the New World wine regions, only the most suitable vines were imported from Europe. These New World wine regions currently have a very limited amount of grape varieties (IV 3). But the history of the region also plays a role in the way how grape growers and wine producers are more resistant to change, thus influencing the general mind-set of the winegrowers (IV 1; IV 10; IV 11):

''You see that a lot that the New World, because it doesn't have all that 'history', is a lot more prone to change. They don't get stuck in tradition. Here in Europe, there is this problem. It's a very big problem. Tradition, authenticity. That is part of the problem, ''we've been doing this for 100 years and we will be doing it for another 100 years''. No mate, you won't be here in 100 years.'' (IV 11)

Over the historic period (1756-now) discussed in chapter 4, Porto & Douro wine region built a large array of legislative framework related to wine production (IV 10). The technical director of the IVDP mentioned:

''I think that we have a lot of legislation to be followed, and over there they don't have it. I would say that the New World is probably more open-minded.'' (IV 10)

Thus, the longer history period in the Porto & Douro wine region has led to a **greater resistance to change** and a **more restrictive legislative framework** that could both hamper sustainable wine production.

8.2.4 The financial means

The CSWA is funded through the two founding associations, both the Wine Institute and the CAWG. For specific projects CSWA receives additional grant from the government, such as the department of agriculture. They funded programmes such as the online tool for the self-assessment (IV 7). Whether such financial means are a possibility in the Porto & Douro region, is unknown. However, the fact remains that government expenditures in the case-study region are being closely observed by the European Union (IV 10; IV 13). Therefore, such financial means are less likely to be a possibility.

8.3 Conclusion New World RSIS wine region comparison

In conclusion, significant differences have been found between the front-runner (New World) of sustainable wine production California and the Old World case-study region Porto & Douro. First of all, California has had an influential sustainability organization devoted to sustainable wine production for 16 years. This organization was realized because mutual consensus on its importance was achieved between the grape growers and the wine producers, as these groups were equally represented through their interest groups. The latter is not possible in the Porto and Douro case-study region as the grape growers are not adequately represented. Because there is no cooperation through a sustainability programme, there is less dialogue and less information sharing between actors within the Porto & Douro wine region. Due to historical reasons, both the general mind-set and the legislative framework of the Porto & Douro wine region are more restrictive to change, hence making a transition to sustainable wine production more difficult. Lastly, the financial situation is different. The Porto & Douro wine region has a lower chance of getting sufficient funding to support the establishment of a sustainability programme devoted to sustainable wine production.

9. Conclusion

With the future agricultural challenges, i.e. growing population and increasingly resource intensive diets, in mind the following research question was devised.

How do the regional and sectoral characteristics of the wine innovation system in the Porto and Douro region in Portugal support or hinder sustainable wine production of the (regional) wine sector and which strategies can be devised to improve the sustainability performance?

As a result from the analysis of the main sustainability challenges, i.e. excessive pesticide use, genetic erosion, water scarcity, social challenges and economic challenges, multiple factors from the RSIS have been identified that support or hinder sustainable wine production in the Porto and Douro region (table 5). Some of these have been confirmed through the analysis of the New World California wine region.

Table 5. The identified factors supporting or hindering sustainable wine production in the Porto and Douro wine region. The factors that were identified in the New World RSIS comparison are checked in the right column.

Hindering factors in the Porto and Douro wine region:	in California:
The financial risk of losing production capacity	
Pesticide use mentality	
Strict legislation regarding irrigation	
Strict regulations regarding grey water use	
Current price of the wines	
Resistance to change	V
The lack of coverage of the regional research institutes	
Lack of transparency	V
Strict legislative framework on port wine	V
Inadequate representation of the farmers	V

Supporting factors in the Porto and Douro wine region:	in California:
Entrepreneurship	
External funds opportunities	V
Increase in tourism	
Growing sustainable wine market	
Increased interest from younger consumers in sustainability aspects	

Ten factors are found that hinder sustainable wine production in the Porto and Douro wine region, and five factors are found that support sustainable wine production in the Porto and Douro wine region. Due to the comparison with California, the inadequate representation of the farmers was discovered. Strategies that can be devised to increase the sustainability performance are connected to the factors that are identified in this study. These strategies are further elaborated in the recommendations for the host organization (chapter 11).

10. Discussion

In this chapter, the theoretical framework limitations are discussed in part 10.1. The methodology limitations are discussed in part 10.2. A refined conceptual framework is presented in part 10.3. The relevance of this study is discussed in part 10.4 and the questions for further research are presented in part 10.5.

10.1 Theoretical limitations of the study

The theoretical framework is designed to find influencing factors on sustainable wine production. Therefore, in this study, the 'sustainability performance' box can only be theoretically approached.

The combination of RIS and SSI elements is rather new. The sectoral approach is the wine sector, and the regional approach is in this case the demarcated wine region and the city of Porto. From the SSI approach, demand changes and knowledge transfers between the global sector have been identified that would not have been discovered whilst using a RIS approach. Likewise, governance institutes would not have been identified the same way whilst using a SSI approach.

The RSIS approach seems very applicable to the wine sector, which consists of many individual geographical regions, that are all connected through global trade and governance organizations such as the International Organization for Vine and Wine (OIV).

10.2 Methodological limitations of the study

Some methodological limitation have been identified during this thesis. The initial devised methodology was to discuss criteria of the RSIS, as presented in table 4. It was quickly discovered that these criteria were too precise and that hence the interviewees were reserved to elaborate on the matter. It worked better to discuss with the interviewees about the sustainability challenge that they are aware of, and to gain insight on the functioning of the RSIS from there.

While introducing to the interviewees, it proved difficult to explain the purpose of the study and the definition of sustainable wine production. Interviewees often had a tendency to primarily think about the economic sense of sustainability. During the interviews, many different sustainability challenges were identified. However, to increase the robustness of the results only the most often identified sustainability challenges have been discussed. This lead to a loss in potential influencing factors of the RSIS on sustainable wine production.

The findings of this study are the result of 15 interviews. However, not all domains are represented to the same extend. Especially the business domain is underrepresented in comparison with the knowledge domains and the governance domains. A top manager of the largest wine company in Portugal has been interviewed, and the sustainability manager of the second largest was also interested. Unfortunately, after many re-scheduling this interview was eventually cancelled. The most common reasons for not cooperating in the study were: general unresponsiveness, lack of proficiency in the English language and too busy schedules.

The New World wine region comparison also has methodological limitations. As discussed in chapter 3, New Zealand was unresponsive to interview requests. Therefore, California was chosen as a front-runner comparison. However, the California wine sector is more like a country by European standards. California has a population of 39 million, compared to the Portuguese population of roughly 10 million. Therefore, the California comparison is more applicable to national comparison rather than regional comparison. Additionally, the CSWA is more on level with the IVV instead of IVDP.

10.3 Refined conceptual framework

The RSIS approach is rather new, and very applicable to the wine sector, as the wine sector is characterized by many different wine regions. One important element to these regions is the domain of history. It has been discussed that regions are characterized by the unique history on political, cultural and economic developments (Cooke, 1997). This history is very connected to the current status of the RSIS. Therefore, for future use of the RSIS approach, it is important to put extra emphasis on the history element, and how the historical events shaped the current situation. When considering future developments, it is essential to understand the history. See figure 22 for a refined conceptual framework.

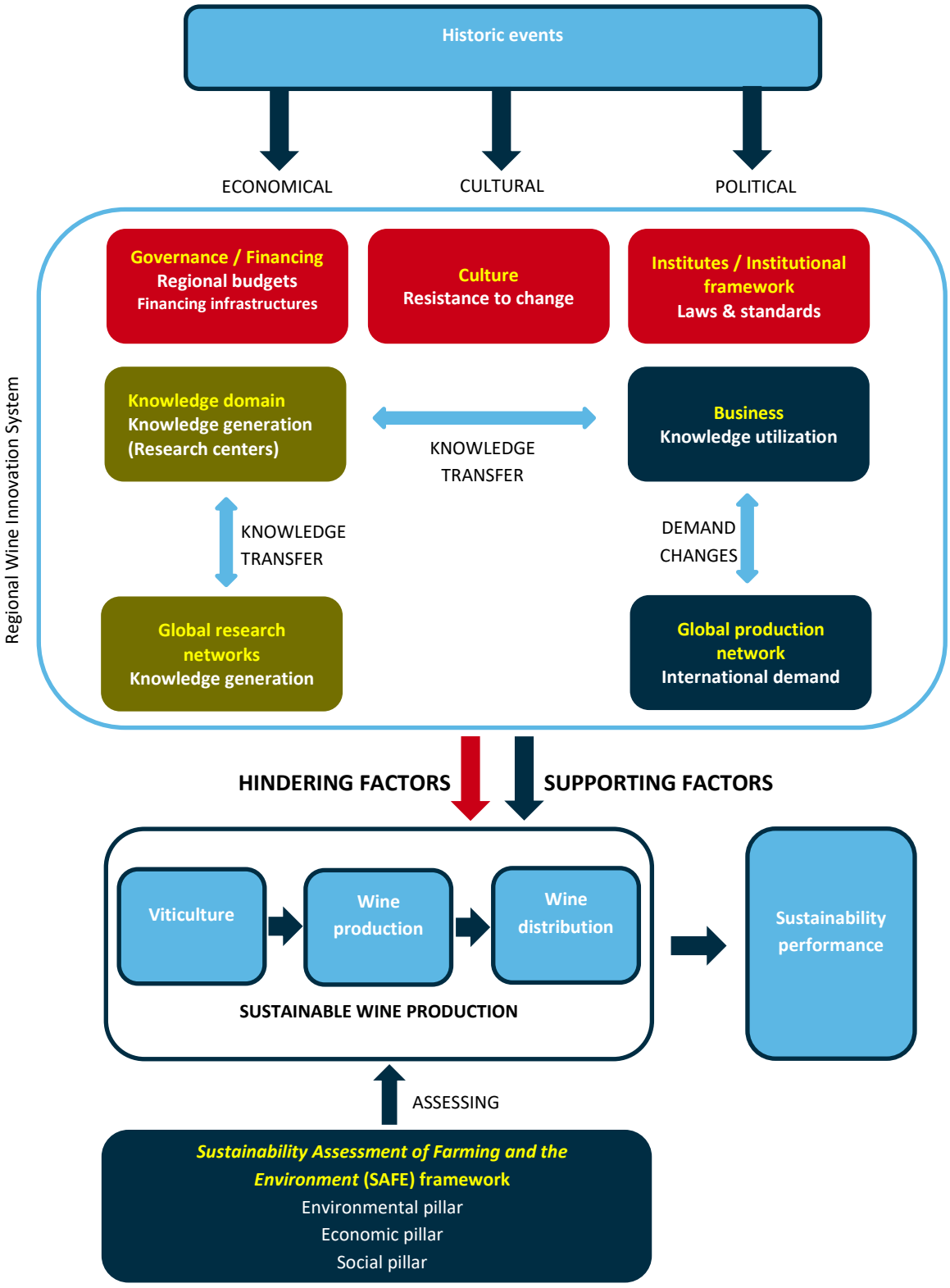

Figure 22. The refined conceptual framework.

10.4 Relevance of the study

The newly devised conceptual framework provides a tool to explore supporting or hindering factors in any wine sector and possibly other agricultural sectors. However, not all agricultural sectors are as geographically independent as the wine sector. When applying the RSIS approach to find supporting or hindering factors to sustainable agricultural production, careful consideration is required of the regional boundaries of the system. In this case-study, the wine region is demarcated, but in other agricultural sectors such geographical boundaries are less common.

Because this study was framed at a regional and sectoral level, the applicability of the results is practically limited to the Porto and Douro wine region. However, as a typical Old World wine region, the findings can be assumed similar to any Old World wine region. The comparison with the front-runner region supported the findings of the Porto and Douro wine region, increasing its validity. Hence, this study contributes to the knowledge of Old World wine regions versus New World wine regions in the field of sustainable wine production.

10.5 Questions for further research

Further research could measure the status quo on sustainability performance in the Porto and Douro wine region. With such measurements executed on multiple points in time, general trends can be observed in relation to sustainable wine production in the region. Additionally, these measurements can provide insight into how much each factor contributes or hinders sustainable wine production and in turn influences sustainability performance.

Furthermore, a topic of research is presented in the price of wine in the Porto and Douro region. Viticulturists identified the market price as too low for the labour and production processes involved. Why are the prices are so low, and what a fair price would be, are topics for further research.

11. Recommendations for the host organization

The main focus of this study was to identify the factors that influence sustainable wine production in the Porto and Douro wine region. A list of these factors is presented in chapter 9. Recommendations related to these factors are presented in part 11.1. Further recommendations, not directly related to the identified factors, are presented in part 11.2.

11.1. Recommendations related to the identified factors

Multiple factors that are identified are within the sphere of influence of the IVDP (Instituto dos Vinhos do Douro e Porto). Mainly the factors that are related to legislation, such as the strict legislation regarding irrigation, the strict regulation regarding grey water use and the strict legislative framework on port wine, are the so-called 'low-hanging fruits'. For example, by allowing for grey water to be used to hydrate the vineyards, the need for irrigation is reduced and the viticultural operations become more sustainable. These developments are essential in light of the increasing temperatures and droughts experienced in the region. It is recommended that the identified sustainability challenges are carefully considered when re-addressing the legislative framework of the Porto and Douro wine sector.

Another element in which the IVDP can play a key role is the establishment of a representative organisation for the farmers. It is identified that for sector-wide sustainability agreements, a dialogue is required between the farmers and the wine producers. The current RSIS situation does not sufficiently support this. Connected to this, the lack of coverage among the farmers of the regional wine research institutes can be addressed. A representative organisation of the farmers should increase the coverage of sustainable wine production knowledge from the research institutes, such as ADVID. It is recommended that the IVDP supports the foundation of an organization to allow for equal negotiating between the wine producers and the farmers in the benefit of sustainable wine production. Alternatively, a council is founded in which voting rights are equally shared between wine producers and farmer representatives, with the purpose to increase sustainability of the Porto and Douro wine region.

Furthermore, it is in the interest of the Porto and Douro sustainable wine production, for the prices of wine to become higher. This will allow for a higher income of the farmers. The increased income allows the farmers to take more risk with regard to pesticide use (organic farming) or other innovative approaches that can increase sustainable wine production. Other means to increase farmers income is to support them in exploring wine tourism possibilities. It is therefore recommended that the IVDP continues to certify the wines according to the determined standards, as history has shown (chapter 4) that an uncontrolled wine region quickly transitions to cheaper wines meant for short-term benefits. Additionally, the IVDP should endeavour to let the average price of wine increase to a, to be determined, fair price. Also, the IVDP should support the farmers that are exploring business opportunities in wine tourism, as it is in the financial benefit of the farmers and in the general benefit of the Porto and Douro wine sector.

The remaining hindering factors; the mentality regarding pesticide use, the resistance to change, the lack of transparency, are culture bound and are the result of generations of experience (chapter 4). Addressing these factors to increase sustainable wine production in the region requires long-term planning involving education on the benefits of information sharing and reducing pesticide use. It is recommended that the IVDP encourages education towards farmers with regard to sustainable wine production.

11.2 Further recommendations

Next to the identified factors of the RSIS influencing sustainable wine production, some separate recommendations are presented.

Currently, strict regulations exist on what farmers take out of the Douro river regarding water consumption, but less focus is given to what substances end up in the Douro river due to run-off by rain. Considering the impacts on biodiversity and on human health, extra focus should be given to the consequences of pesticides that end up in the river system. Therefore it is recommended that scientific developments regarding pesticides in the Douro river should be monitored and the role of the wine sector in this carefully considered.

A large share of the viticultural area in the Porto and Douro wine region is certified under Integrated Production (IV 3). The directives of Integrated Production enhance sustainable wine production, but the programme lacks the familiarity among the wine consumers (IV 11). The demand from the consumers for sustainably produced wines is an important driver for wine producers. Therefore, it is recommended that, if Integrated Production is identified as a desirable sustainable wine programme, Integrated Production becomes better benchmarked.

To enhance sustainable wine production in the Porto and Douro wine region, the *benefício* system can prove as a helpful tool for this purpose. As discussed in chapter 4, the *benefício* system is an evaluation system used to grade viticultural areas on various parameters, for example soil type, altitude, exposure and age of the vineyard. The vineyards can score points on all parameters. The cumulative amount of points determines the final rating of the vineyard, which can be A, B, C, D, E, F, G, H or I. An overview of the *benefício* system is given in appendix 8. To enhance sustainable wine production in the Porto and Douro wine region, it is recommended to use this *benefício* system to reward sustainable wine practices by granting it a higher score. Alternatively the *benefício* system can be given an additional indicator, such as 'A' for standard production and 'A+' for sustainable wine production.

Lastly, it is recommended to consider to introduce a sustainability programme inspired by the New World wine region California, but also by the Portuguese wine region Alentejo. These sustainability programmes increase collaboration and communication between key actors of the wine region, opening the dialogue about sustainable wine production. It creates a more innovative environment, which is an essential development for the Porto and Douro region (Rebelo & Caldas, 2012). The sustainability manager of the WASP has expressed the desire to cooperate and to expand the network to the Porto and Douro region.

Such developments towards sustainable wine production can increase the global competitiveness of the Porto and Douro wine region. As was described by the sustainability manager of the Wines of Alentejo Sustainability Programme:

''A great wine from a region makes no sense. Many great wines, and all of a sudden you have a region'' (IV 11)

12. Reference list

AEVP: Associação das Empresas de Vinho do Porto. (2016). Consulted on 21-07-2016. http://www.aevp.pt/Default

AJAP: Associação de Jovens Agricultores de Portugal. (2016). Consulted on 21-07-2016. http://ajap.pt/.

Alonso, A.D., Liu, Y. (2012). Old wine region, new concept and sustainable development: winery entrepreneurs' perceived benefits from wine tourism on Spain's Canary Islands. *Journal of Sustainable Tourism* 20(7) 991-1009.

Asheim, B.T., Coenen, L. (2006). Contextualising regional innovation systems in a global learning economy: on knowledge bases and institutional frameworks. *Journal of Technology Transfer* 31, 163-173.

Aylward, D.K. (2003). A documentary of innovation support among New World wine industries. *Journal of Wine Research* 14, 31-43.

Banks, G., Overton, J. (2010). Old World, New World, Third World? Reconceptualising the worlds of wine. *Journal of Wine Research* 21 (1), 57-75.

Bassil, K.L., Vakil, C., Sanborn, M., Cole, D.C., Kaur, J.S., Kerr, K.J. (2007). Cancer health effects of pesticides, Systematic review. *Canadian Family Physician* 53, 1704-1711.

Baxter, P., Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report* 13 (4), 544-559

Beard, J. (2006). DDT and human health. *Science of The Total Environment* 355 (1-3), 78-89.

Beckstoffer Vineyards, Farming practices. (2016). Consulted 05-03-2016. http://www.beckstoffervineyards.com/quality/innovation-sustainability/farming-practices/

Beketov, M.A., Kefford, B.J., Schäfer, R.B., Liess, M. (2013). Pesticides reduce regional biodiversity of stream invertebrates. *Proceedings of the National Academy of Sciences* 110 (27), 11039-11043.

Beske, P., Land, A., Seuring, S. (2014). Sustainable supply chain management practices and dynamic capabilities in the food industry: a critical analysis of the literature. *International Journal of Production Economics* 152, 131-143.

Boschma, R.A. (2004). Competitiveness of regions from an evolutionary perspective. *Regional Studies* 38 (9), 1001-1014.

Campbell, G., Guibert, N. (2006). Old World strategies against New World competition in a globalising wine industry. *British Food Journal* 108 (4), 233-242.

Carter, C.R., Easton, P.L. (2011). Sustainable supply chain management: evolution and future directions. *International Journal of Physical Distribution & Logistics Management* 41, 46-62.

Castka, P., Corbett, C.J. (2014). Governance of eco-labels: expert opinion and media coverage. *Journal of Business Ethics*, 1-18.

Cauwenbergh, van N., Bilia, K., Bielders, C., Brouckaert, V., Franchois, L., Garcia Cidad, V., Hermy, M., Mathijs, E., Muys, B., Reijnders, J., Sauvenier, X., Valckx, J., Vanclooster, M., Van der Veken, B., Wauters, E., Peeters, A. (2007). SAFE – A hierarchical framework for assessing the sustainability of agricultural systems. *Agriculture, Ecosystems and Environment* 120, 229-242.

CEEV: Comité Européen des Entreprises Vins. (2016). Consulted on 04-08-2016. http://www.ceev.eu/.

Charles, H., Godfray, J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science* 327, 812-818.

Christ, K.L. & Burritt, R.L. (2013). Critical environmental concerns in wine production: an integrative review. *Journal of Cleaner Production* 52, 232-242.

Climate-Data.org. (2016). Peso da Régua: http://pt.climate-data.org/location/7125/ Link used 18th October 2016. Pinhão: http://pt.climate-data.org/location/489384/ Link used 18th October 2016. Vila Nova de Foz Côa: http://pt.climate-data.org/location/54973/ Link used 18th October 2016.

Coenen, L., Benneworth, P., Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy* 41, 968-979.

Comandaru, I.M., Bârjoveanu, G., Peiu, N., Ene, S.A., Teodosiu, C. (2012). Life cycle assessment of wine: focus on water use impact assessment. *Environmental Engineering and Management Journal* 11 (3), 533-543.

Cooke, P., Uranga, M.G., Etxebarria, G. (1997). Regional innovation systems: Institutional and organisational dimensions. *Research Policy* 26, 475-491.

Cooke, P. (2002). Biotechnology clusters as regional, sectoral innovation systems. *International Regional Science Review 25*, 8-37.

CSWA. (2016). About California Sustainable Winegrowing Alliance. *California Sustainable Winegrowing Alliance*. Consulted on 21-07-2016. http://www.sustainablewinegrowing.org/aboutcswa.php

Cusmano, L., Morrison, A., Rabellotti, R. (2010). Catching up trajectories in the wine sector: A comparative study of Chile, Italy, and South Africa. *World Development* 38 (11), 1588-1602.

Delmas, M.A. (2010). Perception of eco-labels: organic and biodynamic wines. *UCLA Institute of the Environment,* 09-10.

Delmas, M.A., Grant, L.E. (2014). Eco-labeling strategies and price-premium: the wine industry puzzle. *Business & Society* 53, 6-44.

Dodds, R., Graci, S., Ko, S., Walker, L. (2013). What drives environmental sustainability in the New Zealand wine industry? An examination of driving factors and practices. *International Journal of Wine Business Research* 25(3), 164-184.

DouroValley.eu. (2016). History of the Region. http://dourovalley.eu/en/history_region_1, used 12-11-2016.

EU 203. (2012). Commsion implementing regulation (EU) No 203/2012, amending Regulation (EC) No 889/2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007, as regards detailed rules on organic wine. *Official Journal of the European Union* L 71, 42-47.

ENRD. (2014). Improving the Environment through Integrated Production of Grapevines. *European Network for Rural Development. Digitally available at: http://enrd.ec.europa.eu/enrd-static/policy-in-action/rdp_view/en/view_project_10280_en.html.*

FAOSTAT: Food and Agriculture Organisation of the United Nations, Country Indicators Portugal. (2016). Consulted 2-11-2016. http://faostat.fao.org/beta/en/#country/174.

Feio, A., Correia Guedes, M. (2013). Architecture, tourism and sustainable development for the Douro region. *Renewable Energy* 49, 72-76.

Figueiredo, T., Poesen, J., Gonçalves Ferreira, A. (1998). The relative importance of low frequency erosion events: results from erosion plots under vineyards in the Douro region, Northeast-Portugal. *Proceedings of the 16th world congress of soil science, Montpellier.*

Flint, D.J., Golicic, S.L. (2009). Searching for competitive advantage through sustainability: A qualitative study in the New Zealand wine industry. *International Journal of Distribution & Logistics Management* 39, 841-860.

Fraga, H., Malheiro, A.C., Moutinho-Pereira, J., Santos, J.A. (2012). An overview of climate change impacts on European viticulture. *Food and Energy Security 2012* 1 (2), 94-110.

Freeman, C. (1987). Technology and Economic Performance: Lessons from Japan, *Frances Pinter*, London.

Gabzdylova, B., Raffensperger, J.F., Castka, P. (2009). Sustainability in the New Zealand wine industry: drivers, stakeholders and practices. *Journal of Cleaner Production* 17, 992-998.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P.K., Toulmin, C., Vermeulen, S.J., Godfray, H.C.J. (2013). Sustainable intensification in agriculture: premises and policies. *Science* 341, 33-34.

Gerstlberger, W. (2004). Regional innovation systems and sustainability – selected examples of international discussion. *Technovation* 24, 749-758.

Girardin, P., Bockstaller, C., Van der Werf, H. (2000). Assessment of potential impacts of agricultural practices on the environment: the AGRO*ECO method. *Environmental Impact Assessment Review* 20, 227-239.

Hajek, P., Henriques, R., Hajkova, V. (2014). Visualising components of regional innovation systems using self-organizing maps – evidence from European regions. *Technological Forecasting & Social Change* 84, 197-214.

Hall, M., Mitchell, R. (2000). Wine tourism in the Mediterranean: A tool for restructuring and development. *Thunderbird International Business Review* 42(4), 445-465

INIAV: Instituto Nacional de Investigação Agrária e Veterinária. (2016). Consulted on 21-07-2016. http://www.iniav.pt/gca/index.php?id=1113

Initiative, C. S., Golden, J. S., Vermeer, D., Clemen, B., & Davie Nguyen, M. E. M. (2010). An overview of ecolabels and sustainability certifications in the global marketplace. *Nicholas Institute for Environmental Policy Solutions. Duke University. Interim Report Document*, 10-1.

International Energy Agency. (2016). Consulted: 18-02-2016. http://www.iea.org/publications/scenariosandprojections/

Instituto dos Vinhos do Douro e Porto (IVDP), section Estatistica, Produção de vinho generose e vinho muscatel General (2008-2014). Consulted: 02-02-2016. https://www.ivdp.pt/pagina.asp?codPag=86&codSeccao=6&idioma=0

IOBC: International Organisation for Biological Control. (2016). Consulted on: 15-06-2016. http://www.iobc-global.org/about_iobc.html

IOBC. (2007). IOBC-WPRS IP & IPM: Crop specific Integrated Production Guidelines. *International Organisation for Biological Control.* Digitally available at: http://www.iobc-wprs.org/ip_ipm/IP_guidelines_crop_sprecific.html

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IVDP: Instituto dos Vinhos do Douro e Porto. (2016). Consulted on 21-07-2016. https://www.ivdp.pt/index.asp?idioma=1&

IVV: Instituto da Vinha e do Vinho, I.P. (2016). Consulted on 21-07-2016. http://www.ivv.min-agricultura.pt/np4/27.

Jacobsson, S., Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions* 1, 41-57.

Jones, G.V., Alves, F. (2012). Impacts of climate change on wine production: a global overview and regional assessment in the Douro valley of Portugal. *International Journal of Global Warming* 4 (3-4), 383-406.

Klerkx, L., Schut, M., Leeuwis, C., Kilelu, C. (2012). Advances in knowledge brokering in the agricultural sector: towards innovation system facilitation. *IDS Institute of Development Studies* 43, 53-60.

Knill, C., Heichel, S., Arndt, D. (2012). Really a front-runner, really a straggler? Of environmental leaders and laggards in the European Union and beyond – a quantitative policy perspective. *Energy Policy* 48, 36-45.

Krabbe, G., Linthorst, G., Blok, K., Crijns-Graus, W., van Vuuren, D.P., Höhne, N., Faria, P., Aden, N., Carrillo Pineda, A. (2015). Aligning corporate greenhouse-gas emissions targets with climate goals. *Nature Climate Change* 5, 1057-1060.

Lammerts van Bueren, F., Blom, F. (1997). Hierarchical Framework for the formulation for sustainable forest management standards: principles, criteria and indicators. *Tropenbos Foundation, Wageningen, The Netherlands.*

Lewis, K.A., Bardon, K.S. (1998). A computer-based informal environmental management system for agriculture. *Environmental Modelling Software* 13, 123-137.

Malavolta, C., Boller, E.F. (2007). Guidelines for integrated production of grapes. *IOBC wprs Bulletin* 46, 1-21.

Markard, J., Raven, R., Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy* 41, 955-967.

Mascarenhas, A., Coelho, P., Subtil, E., Ramos, T.B. (2010). The role of common local indicators in regional susutainability assessment. *Ecological Indicators* 10, 646-656.

McEwan, C., Bek, D. (2009). The political economy of alternative trade: Social and environmental certification in the South African wine industry. *Journal of Rural Studies* 25, 255-266.

Morrison, A., Rabellotti, R. (2006). The role of research in wine: The emergence of a regional research area in an Italian wine production system. *46th Congress of the European Regional Science Association: ''Enlargement, Southern Europe and the Mediterranean'',* August 30th, September 3rd, 2006, Volos, Greece.

Morrison, A., Rabellotti, R. (2009). Knowledge and information networks in an Italian wine cluster. *European Planning Studies* 17 (7), 983-1006.

Neto, B., Dias, A.C., Machado, M. (2013). Life cycle assessment of the supply chain of a Portuguese wine: from viticulture to distribution. *International Journal of Life Cycle Assessment* 18, 590-602.

OEC. (1997). National Innovation Systems.
OEC Publishing. http://www.oecd.org/science/inno/2101733.pdf

OECD. (2013). Agricultural Innovation Systems, A framework for analysing the role of the government. OECD Publishing. http://dx.doi.org/10.1787/9789264200593-en

OIV: International Organisation of Vine and Wine. (2016). Consulted on 13-06-2016. http://www.oiv.int/

Parliament. (2009). Industry and innovation in the north east of England – North east regional committee contents. *Memorandum from the centre for knowledge, innovation, technology and enterprise (KITE),* Newcastle University.
http://www.publications.parliament.uk/pa/cm200910/cmselect/cmneast/169/169we06.htm

Pattara, C., Raggi, A., Cichelli, A. (2012). Life cycle assessment and carbon footprint in the wine supply chain. *Environmental Management* 49, 1247-1258.

Paulo Martins, J. (2011). The Pleasure of Port - *The inside story of a unique fortified wine*. PublicaCOes Dom Quixote. ISBN: 978-972-20-4661-9.

Pizzigallo, A.C.I., Granai, C., Borsa, S. (2008). The joint use of LCA and energy evaluation for the analysis of two Italian wine farms. *Journal of Environmental Management* 86, 396-406.

Plessis, M. du. (2007). The role of knowledge management in innovation. *Journal of knowledge management* 11 (4), 20-29.

Point, E., Tyedmers, P., Naugler, C. (2012). Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. Journal of Cleaner Production 27, 11-20.

Potts, T. (2010). The natural advantage of regions: linking sustainability, innovation, and regional development in Australia. *Journal of Cleaner Production* 18, 713-725.

Pope, J., Annandale, D., Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. *Environmental Impact Assessment Review* 24, 595-616.

Pullman, M.E., Maloni, M.J., Dillard, J. (2010). Sustainability practices in food supply chains: How is wine different? *Journal of Wine Research* 21, 35-56.

Ras, P.J., Vermeulen, W.J.V. (2009). Sustainable production and performance of South African entrepreneurs in a global supply chain. The case of South African table grape producers. *Sustainable Development* 17, 325-340.

Rebelo, J., Caldas, J. (2012). The Douro wine region: a cluster approach. *Journal of Wine Research* 24, 19-37.

Rebelo, J., Caldas, J., Guedes, A. (2015). The Douro Region: Wine and Tourism. *Journal of Tourism, Culture and Territorial Development* 6 (11), 75-90.

Rita Ribeiro, A., Maia, A., Santos, M., Elizabeth Tiritan, M., Maria Rosa Ribeiro, C. (2016). Occurrence of natural contaminants of emerging concern in the Douro river estuary, Portugal. *Archives of Environmental Contamination and Toxicology* 70, 361-371.

Rolandi, S., Saba, A. (2015). Voluntary certification systems in the EU wine sector: How to recognise quality and be safe from confusion. *BIO Web of Conferences (38th World Congress of Vine and Wine)* 5, 1-6.

Sands, R.D., Jones, C.A., Marshall, E. (2014). Global drivers of agriculture demand and supply. United States Department of Agriculture, *Economic Research Report* 174.

Santini, C., Cavicchi, A., Casini, L. (2013). Sustainability in the wine industry: key questions and research trends. *Agricultural and Food Economics* 1, 1-14.

Santos, J.A., Grätsch, S.D., Karremann, K., Jones, G.V., Pinto, J.G. (2013). Ensemble projections for wine production in the Douro Valley of Portugal. *Climate Change* 117, 211-225.

Sauvenier, X., Valckx, J., Van Cauwenbergh, N., Wauters, E., Bachev, H., Biala, K., Bielders, C., Brouckaert, V., Garcia Cidad, V., Goyens, S., Hermy, M., Mathijs, E., Muys, B., Vanclooster, M., Peeters., A. (2006). Framework for assessing sustainability levels in Belgian agricultural systems – SAFE. Part 1: Sustainable production and consumption patterns. Final Report-SPSD II CP 28. *Belgian Science Policy*, Brussels, Belgium, 125 pp.

Séralini, G.E., Clair, E., Mesnage, R., Gress, S., Defrage, N., Malatesta, M., Hennquin, D., Spiroux de Vendômois, J. (2014). Long-term toxicity of a Roundup herbicide and a Roundup tolerant genetically modified maize. *Environmental Sciences Europe* 26

Slaper, T.F., Hall, T.J. (2011). The triple bottom line: what is it and how does it work? *Indiana Business Review Spring* 2011, 4-8.

Smith P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E.A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N.H. Ravindranath, C.W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, F. Tubiello. (2014): Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Styles, D., Schoenberger, H., Galves-Martos, J.L. (2012). Environmental improvement of product supply chains: A review of European retailers' performance. Resources, *Conservation and Recycling* 65, 57-78.

Taylor. (2016), History of Port – The early wine trade. http://www.taylor.pt/en/what-is-port-wine/history-of-port/ Used: 15-11-2016.

Tödtling, F., Trippl, M. (2005). One size fits all? Towards a differentiated regional innovation policy approach. *Research Policy* 34, 1203-1219.

Tomlinson, I. (2013). Doubling food production to feed the 9 billion: A critical perspective on a key discourse of food security in the UK. *Journal of Rural Studies* 29, 81-90.

Tseng, M-L. (2013). Modelling sustainable production indicators with linguistic preferences. *Journal of Cleaner Production* 40, 46-56.

United Nations. (2015). World population prospects: key findings & advance tables 2015 revision. *Department of Economic and Social Affairs. New York.*
http://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf

UNESCO. (2016). Alto Douro Wine Region. Consulted on 06-03-2016.
http://whc.unesco.org/en/list/1046

Vecchio, R. (2013). Determinants of willingness-to-pay for sustainable wine: Evidence from experimental auctions. *Wine Economics and Policy* 2, 85-92.

Villanueva-Rey, P., Vázquez-Rowe, I., Teresa Moreira, M., Feijoo, G. (2014). Comparitive life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. *Journal of Cleaner Production* 65, 330-341.

Viret, O. (2013). Viticulture in Switzerland and Integrated Production of Grape. *Federal Department of Economic Affairs, Education and Research*. Digitally available at http://www.iobc-wprs.org/pub/2013_WG_Viticulture_meeting_Ascona_CH/12-Viret_Viticulture.pdf

Wisecrop. (2016). Consulted on 29-11-2016. https://www.wisecrop.com/pt/.

Yin, R.K. (2013). Case Study Research – Design and Methods 5th edition. *Sage Publications*, 2013.

Zahm, F., Viaux, P., Vilain, L., Girardin, P., Mouchet, C. (2008). Assessing farm sustainability with the IDEA method – from the concept of agriculture sustainability to the case studies on farms. *Sustainable Development* 16, 271-281.

Zucca, G., Smith, D.E., Mitry, D.J. (2009). Sustainable viticulture and winery practices in California: What is it, and do customers care? *International Journal of Wine Research* 2, 189-194.

12.1 Figure sources

Figure 6

1. Grahams Port, Douro Harvest Report 2015. Link used on 10-11-2016 https://blog.grahams-port.com/tag/2015-vintage/
2. Niepoort Vinhos. Link used on 10-11-2016 http://www.niepoort/vinhos.com/common/douro/images/river.jpg
3. Food and Wine Portugal, Portuguese Port Wine. Link used on 10-11-2016 http://foodandwineportugal.com/tag/portuguese-port-wine/
4. Grahams Port. Link used on 10-11-2016 https://malvedos.files.wordpress.com/2010/10/lagar-14.jpg

13. Appendix

Appendix 1: The sustainability principles and corresponding criteria, retrieved from Cauwenbergh *et al*., (2007).

Principles	Criteria
Environmental pillar	
Air	
Supply (flow) of quality air function	Air quality is maintained or enhanced
Air flow buffering function	Wind speed is adequately buffered
Soil	
Supply (stock) of soil function	Soil loss is minimized
Supply (stock) of quality soil function	Soil chemical quality is maintained or increased Soil physical quality is maintained or increased
Soil flow buffering function	Soil mass flux (mudflows, landslides) are adequately buffered
Water	
Supply (flow) of water function	Adequate amount of surface water is supplied Adequate amount of soil moisture is supplied Adequate amount of groundwater is supplied
Supply (flow) of quality water function	Surface water of adequate quality is supplied Soil water of adequate quality is supplied Groundwater of adequate quality is supplied
Water flow buffering function	Flooding and runoff regulation of the agro-ecosystem is maintained or enhanced
Energy	
Supply (flow) of exergy function	Adequate amount of exergy is supplied
Energy flow buffering function	Energy flow is adequately buffered
Biodiversity	
Supply (stock) of biotic resources function	Planned biodiversity is maintained or increased Functional part of spontaneous biodiversity is maintained or increased Heritage part of spontaneous biodiversity is maintained or increased
Supply (stock) of habitat function	Diversity of habitats is maintained or increased
Supply (stock) of quality habitat function	Functional quality of habitats is maintained or increased
Biotic resource flow buffering function	Flow of biotic resources is adequately buffered
Economic pillar	
Viability	
Economic function	Farm income is ensured Dependency on direct and indirect subsidies is minimized Dependency on external finance is optimal Agricultural activities are economically efficient Agricultural activities are technically efficient Market activities are optimal Farmer's professional training is optimal Inter-generational continuation of farming activity is ensured Land tenure arrangements are optimal Adaptability of the farm is sufficient
Social pillar	
Food security and safety	
Production function	Production capacity is compatible with society's demand for food Quality of food and raw materials is increased Diversity of food and raw materials is increased Adequate amount of agricultural land is maintained
Quality of life	
Physical well-being of the farming community function	Labour conditions are optimal Health of the farming community is acceptable
Psychological well-being of the farming community function	Education of farmers and farm workers is optimal Internal family situation, including equality in the man–woman relation is acceptable Family access to and use of social infrastructures and services is acceptable Family access to and participation in local activities is acceptable Family integration in the local and agricultural society is acceptable

Appendix 2: The interview questions

Date:
Time:
Interviewer:
Interviewee:
Communication means (skype/phone/personal):

Thank the interviewee for the opportunity of this interview, explain the interviewee about the use of the data, why the conversation is being recorded and that a summary of the transcript will be sent afterwards for approval. Explain the definition of an innovation system, sustainability, a sustainability transition and a sustainable wine production. Explain the purpose of this study (to find out how the innovation system is affecting the implementation of sustainable wine production). Mention that any words used in this interview that are considered difficult can be further explained. The interviewer takes a graphical representation of the regional wine innovation system. Main research question is given:

How do the regional and sectoral characteristics of the wine innovation system in the Porto and Douro region in Portugal support or hinder sustainable wine production of the (regional) wine sector and which strategies can be devised to improve the sustainability performance?

General questions
Q1: What is your position/job/function in the in relation to the Porto and Douro wine sector? And for how long?

Q2: What does sustainable wine production mean according to you?

Q3: Do you know of sustainable wine production that has been implemented in the Douro and/or Porto area? *(test this sustainable wine production on sustainability through the indicators of the SAFE framework)*

Q4: How and when did the process of implementation initiate? And how was it executed? By whom was it executed and what was their role in the process?

Q5: New World wine regions (New Zealand, Australia, California) seem to have thorough sustainability strategies opposed to Old World wine regions (Portugal, Spain, Italy), does this difference in your opinion exist and what causes this difference according to you?

Q6: According to you, what are the greatest sustainability issues in this wine region?

Q7: Are these issues difficult to solve, why? And who should solve it, why?

Q8: If any, what sustainability issues were tackled in the history?

Q9: How were these tackled and by whom? Which actors were involved and how were they related?

Learning and Innovation
Q10: How do the actors in the innovation system operate in informal (non-organized) networks?

Q11: How do the actors in the innovation system have a willingness to cooperate?

Institutional framework
Q12: Would you describe the culture in this wine region as a culture of cooperation or as a culture of non-cooperation? Why?

Q13: Which of the following would describe the culture of the wine region the best: Culture of cooperation, associative culture, learning culture, productive culture. Could you give an illustration of this?

Q14: Does the wine region have the experience and ability to carry out or incorporate institutional changes? Why yes/no? If yes, which?

Q15: How is the university properly linked to the productive system?

Knowledge domains
Q16: How are the knowledge domains, which are the main scientific and technological actors at the basis which provide the essential knowledge to undertake innovative activities, implemented in the innovation system?

Demand
Q17: How is the demand changing for sustainable (and or organic/biological) produced wines?

Actors and networks
Q18: What kind of relationship exists within the key actors? How come? And how strong?

Q19: Which public research organizations present in the key actor networks?

Institutions
Q20: Is the regulation of standards and procedures strict or non-strict? Why?

Financing
Q21: Is there a budget for the regions autonomous policy? If yes, how much? And on which level? Regional/national?

Q22: Which influence has the regional innovation system on the design and execution of basic infrastructures?

Finalizing
Q23: How can entrepreneurship contribute to a more sustainable wine production in this region?

Q24: Do you have any final remarks or questions? Could you further improve the innovation system model that I made?

Thank the interviewee again for the opportunity. Mention that the transcribed and summarized interview result will be sent for approval within a mentioned timeframe.

Appendix 3. The sustainability indicators of the SAFE framework as retrieved from Sauvier *et al.*, (2006).

PRINCIPLES	CRITERIA	INDICATORS	Description	Unit	Measurement scale	Expression scale	Source
ENVIRONMENTAL PILLAR							
ECOSYSTEM INTEGRITY							
Ecosystem stability regulation function	Resistance and resilience of the ecosystem is maintained/increased	Ratio of net radiation flux and incoming net solar radiation (Rn/K)	Ratio of the net radiation transformed into nonradiative energy at the soil surface and the short wave radiation balance (the higher this ratio, the higher the system's ability to dissipate the radiative gradient, the more integer the ecosystem)	no unit	E	E	Kutsch *et al.*, 2001
		Free net primary biomass productivity	The amount of biomass free for the spontaneous development of the ecosystem, to fulfil its life support functions and to support the food web	$t\ ha^{-1}$	E	E	Lindeyer, 1998; Blonk & Lindeyer, 1995
AIR							
Supply of quality air function	Air quality is maintained/enhanced	Methane emission (CH_4)	Estimation of methane emitted by the system	$t\ eqCO_2.ha^{-1}.yr^{-1}$	F	F	Siterem, 2001
		Ammonia emission (NH_3)	Estimation of ammonia emitted by the system	$t\ eqA.ha^{-1}.yr^{-1}$	F	F	Siterem, 2001
		Nitrous oxide emission (N_2O)	Estimation of nitrous oxide emitted by the system	$t\ eqCO_2.ha^{-1}.yr^{-1}$	F	F	Siterem, 2001
		Indirect carbon dioxide emissions (CO_2)	Estimation of carbon dioxide emitted during the synthesis of mineral nitrogen fertilizers spread on the farm	$t\ eqCO_2.ha^{-1}.yr^{-1}$	F	F	SAFE
		Pesticide Risk Score (RS) to air	Risk for presence of pesticide residues in the air compartment	no unit [-10→10]	P	P/F	POCER-2 (Maraite *et al.*, 2005)
Air buffering function	Wind speed is adequately buffered	Land use pattern	Organisation/orientation/proportion of different landuse types in the landscape, landuse being series of activities undertaken to produce one or more goods or services	no unit	Catch.	Catch.	FRAGSTATS (McGarigal and Marks, 1994)
SOIL							
Stock of soil function	Soil loss is minimised	Water erosion risk	Risk for soil loss caused by water as calculated by USLE equation Erosion = R K C LS P. Long term yearly average value.	$t.ha^{-1}.yr^{-1}$	P/C	P/F	OECD, after USLE, modeled by WATEM (Van Oost *et al.*, 2000)
		Harvest erosion	Loss of soil occurring during harvest operations ~ Amount of non-agricultural product (leaves, dirt, soil) present at the factory.	$t\ ha^{-1}$	C	P-C-F	SAFE; Poesen *et al.*, 2001
		Tillage erosion risk	Risk for transport of the soil caused by tillage activities	$t.ha^{-1}.yr^{-1}$	P	P/F	modeled by WATEM (Van Oost *et al.*, 1999)
Stock of quality soil function	Soil chemical quality is maintained/increased	Soil organic carbon content	Organic carbon content	%	P	P/F	Doran & Parkin, 1994
		Soil acidiy - pH	pH	no unit	P	P/F	Doran & Parkin, 1994
		Phosphorus P	Phosphorus content	$mg.kg^{-1}$	P	P/F	
		Nitrogen N	Total nitrogen content	$mg.kg^{-1}$	P	P/F	
		Pesticide residues	Risk for presence of pesticide residues in the liquid phase of soil	no unit [-10→10]	P-F	P/F	POCER-2 (Maraite *et al.*2005)
		Nitrogen Annual Balance	Input of nitrogen from different sources minus output of nitrogen in vegetal and animal production (over one year)	$kg\ N.ha^{-1}.yr^{-1}$	P	P/F	OECD
		Phosphorus Annual Balance	Input of phosphorus from different sources minus output of phosphorus in vegetal and animal production (over one year)	$kg\ P.ha^{-1}.yr^{-1}$	P	P/F	OECD
		Potassium Annual Balance	Input of potassium from different sources minus output of potassium in vegetal and animal production (over one year)	$kg\ K.ha^{-1}.yr^{-1}$	P	P/F	OECD
		Addition of heavy metals	Total amount of heavy metals added to the soil, originating from amendments	$mg.kg^{-1}$	P	P/F	Arshad and Martin, 2002
	Soil physical quality is maintained/increased	Soil organic carbon input	Input of organic carbon in soil under form of amendments, harvest residues, etc.	$kg.ha^{-1}.$	P	P/F	SAFE
		Soil carbon balance	Input minus output of carbon in soil	$kg.ha^{-1}.$	P	P/F	OECD
		Tillage pressure	Cumulated depth of soil work on a parcel, all types of machines included	$cm.yr^{-1}$	P	P-F	SAFE
		Compaction risk	Risk for compaction of soil (= decreasing porosity or increasing dry bulk density (BD) as a result of firm-pack soil particles ([McKyes, 1985]) due to pressure provoked by tillage activities	no unit	C	P/F	SAFE
WATER							
Supply of water function	Adequate amount of surface water is supplied	Surface water balance	Input minus output of surface water under different forms in a specified area	$m^3.ha^{-1}.$	Catch	Catch	after ECNC, modelled by SWAT (Arnold & Allen, 1993)
	Adequate amount of soil moisture is supplied	Irrigation practices	Practices of artificial application of water to lands for agricultural purposes (expressed as % of irrigated land of total arable land)	%	C	F	OECD
		Drought stress	Stress to plant growth related to the cumulative effects of either an absolute or an abnormal transpiration deficit caused by a prolonged absence or marked deficiency of precipitation	$number.yr^{-1}$	P	P-F	after ECNC; modelled by WAVE (Vereecken *et al.*, 1991)
	Adequate amount of ground water is supplied	Groundwater level	Elevation, at a certain location and time, of the water table or piezometric surface of an aquifer	m	P	P-F	ECNC (p77), (methods for soil analysis p547)
		Water consumption	Amount of water consumed during agricultural activities on farm	$m^3.\ yr^{-1}$	F	F	OECD
Supply of quality water function	Surface water of adequate quality is supplied	Pesticide runoff risk	Risk for transport of pesticides to small ponds and rivers by the part of precipitation that appears as streamflow	$kg.ha^{-1}.yr^{-1}$	P	P-F-L	SAFE (recommended but not developed by OECD); modelled by SWAT (Arnold & Allen, 1993)
		Presence of grass strips/riparian areas	Presence of strips planted with grass adjacent to fields or of riparian areas whicare lands directly adjacent to rivers and streams. Both can potentially buffer streams from the impacts of agriculture	$m^2.\ ha^{-1}$	F-L	F-L	VLM, DGRNE

	Soil water of adequate quality is supplied	Pesticide residues	Risk for presence of pesticide residues in the liquid phase of soil	no unit [-10→10]	P-F	P-F	POCER-2 (Maraite *et al.*2005)
	Groundwater of adequate quality is supplied	Vegetation cover during nitrate leaching period	Percentage of days that soil is 'covered' by vegetation during the particular nitrate leaching period (15-09 → 15-01) (covered = between sowing and harvest)	% (of days)	P	P-F	SAFE
		Good agricultural practices	Percentage of positive answers in a questionnaire on good pest management and fertilization practices	% (of positive answers)	F	F	SAFE
		Soil link rate - 2 (SL-2)	Ratio between the nitrogen that is spread on the farm and the nitrogen that can be used by the plants, importations and exportations contracts included	no unit	F	F	Gouvernement wallon, 2002
		Potentially Leachable Nitrogen - PLN	Nitrate content in the soil profile in November	kg $N\text{-}NO_3^-.ha^{-1}$	P	P-F	Ministère de l'Aménagement du Territoire, de l'Urbanisme et de l'Environnement, 2004.
		Nitrogen Systemic Balance (cropping plan scale) - NSB_{cp}	$NSB_{cropping\ plan}$ = (N Input) – (N Output) = N losses (denitrifiction, volatilisation, leaching & runoff) + Δ Humus.	$kg\ N.ha^{-1}.yr^{-1}$	CP	CP	Ministère de l'Aménagement du Territoire, de l'Urbanisme et de l'Environnement, 2004.
Water buffering function	Flooding and run-off regulation function of the agro-ecosystem shall be maintained/enhanced	Runoff risk	Risk for transport of soil from agricultural fields to small ponds and rivers by the part of precipitation that appears as streamflow	$kg.ha^{-1}.yr^{-1}$	P-F-L	P-F-L	SWAT (Arnold & Allen, 1993)
		Soil cover index	Index indicating the extent of soil cover by vegetation	no unit	P	P-F-L	Revised Universal Soil Loss equation (RUSLE) (Renard *et al,* 2003).
		Vegetation cover	Percentage of soil cover by vegetation (in contrast to nude soil parts)	%	P	P-F-L	SAFE
		Presence of grass strips/riparian areas	Presence of strips planted with grass adjacent to fields or of riparian areas whicare lands directly adjacent to rivers and streams. Both can potentially buffer streams from the impacts of agriculture	$m^2.\ ha^{-1}$	F-L	F-L	VLM, DGRNE
ENERGY							
Supply of energy function	Adequate amount of energy is supplied	Direct energy output	Energy output produced by means of recycling (e.g. methanisation), windmills, capture of solar energy… or contained in energetic crops (under contract) and exported out of the farm, per ha of AA	$GJ.ha^{-1}$	F	F-R	SAFE
Energy flow buffering function	Energy flow is adequately buffered	Direct energy input	Energy input used for the production of agricultural products (until it is sold or leaves the farm or is used as fodder for livestock) that can be directly converted into energy units (diesel-fuel, electricity and lubricants), per ha	$GJ.ha^{-1}$	F	F	Dalgaard *et al.*, 2001.
		Renewable direct energy input	Direct energy input of a farm that is renewable	$GJ.ha^{-1}$	F	F	SAFE and Dalgaard *et al.*, 2001.
		Energy balance	((Direct & indirect energy output - (Direct & indirect energy input)	$GJ.ha^{-1}$	F	F	SAFE and Dalgaard *et al.*, 2001.

BIODIVERSITY							
A. Biotic Resources							
Stock of biotic resources function	Planned biodiversity is maintained/increased	Number of crop species	Number of crop species cultivated on the AA (culture and interculture)	n°	F	F-R	SAFE
		Number of threatened and rare crop varieties	Number of threatened and rare crop varieties cultivated on the AA (culture and interculture)	n°	F	F-R	PAEXA, 2000. (based on Agri-Environmental Measures of the Walloon Region)
		Number of livestock species	Number of livestock species raised by the system	n°	F	F-R	SAFE
		Number of threatened and rare livestock breeds	Number of threatened and rare livestock breeds raised by the system	n°	F	F-R	SAFE (based on Agri-Environmental Measures of the Walloon Region)
	Functional part of natural/spontaneous biodiversity is maintained/increased	Total number of wild plant species in permanent grassland	Total number of wild plant species occurring in permanent grassland (inventory)	n°	P	P-F	SAFE
		Soil biological activity	Soil microbial community composition	n°	P	P	SAFE
		Earthworm species saturation	The proportion of earthworm species present in the farmer's parcels in relation with the potential earthworm species pool of agro-ecosystems	%	P	P-F	SAFE; Hermy & Cornelis, 2000
	Heritage part of natural/spontanous biodiversity is maintained/increased	Butterfly species saturation	The proportion of butterfly species present in relation with a regional butterfly species pool potentially occurring in the agro-ecosystem.	%	T	F/L	SAFE; Hermy & Cornelis, 2000
		Number of protected and Red List butterfly species	The number of present butterfly species protected by supranational, national or regional legislations or mentioned in the Red List.	n°	T	F/L	SAFE
		Breeding bird species saturation	The proportion of present breeding bird species in relation with a regional breeding bird species pool potentially occurring in the agro-ecosystem.	%	T	F/L	SAFE; Hermy & Cornelis, 2000
		Number of protected and Red List bird species	The number of the present bird species (winter visitors/residents and breeding birds) protected by supranational, national or regional legislations or mentioned in the Red List.	n°	T	F/L	SAFE
		Number of European Bird Directive species	The number of present bird species (winter visitors/residents and breeding birds) mentioned in the European Bird Directive.	n°	T	F/L	SAFE
		Wild flora species saturation	The proportion of present wild flora species in relation with a regional wild flora species pool potentially occurring in the agro-ecosystem.	%	P	P/F/L	SAFE; Hermy & Cornelis, 2000
		Number of protected and Red List wild flora species	The number of present wild flora species protected by supranational, national or regional legislation or mentioned in the Red List	n°	P	P/F/L	SAFE
		Total number of wild plant species in permanent grassland	Total number of wild plant species occurring in permanent grassland (inventory)	n°	P	P-F	SAFE
		Pesticide Risk Score to biodiversity (POCER-2 RS)	Equal weights average of pesticide Risk Scores (RS) to five biodiversity compartments: birds, bees, beneficials and water organisms.	no unit [-10→10]	P	P-F	POCER-2 (Maraite *et al.*, 2005)
		Fertilizer pressure on Natura 2000 grasslands	Amount of N and P (min/org) spread by ha, on Natura 2000 grasslands	U $N, P.ha^{-1}$	P	P-F	SAFE
		Proportion of high biological value meadows in permanent grassland	Surface proportion of high biological value meadows that are cut late after a specified date (Mesures agri-environnementales", RW).	%	F	F	SAFE

		Existence of special devices for wild fauna	Number of significant types of devices for wild fauna (e.g.: nesting boxes, nests, corn heads...) on the farm and on the farmland.	n°	F	F	SAFE
B. Habitats							
Stock of habitat function	Diversity of habitats is maintained/increased	Habitat saturation	The proportion of habitats that is present in a landscape surrounding the farm in relation with a list of habitats that can potentially be found in agro-ecosystems	%	F/L	F / L	SAFE; Hermy & Cornelis, 2000
		Agricultural area under management contract	The area of agricultural land for which the farmer has entered into a management contract (e.g meadow birds, parcel margins, small landscape elements, botanical management)	ha	P	F/L	SAFE; Hermy & Cornelis, 2000
		Agricultural area managed for wild biota without management contract	The area of agricultural land that is ecologically managed by the farmer but for which he has not entered into a management contract	ha	P	F/L	SAFE
		Agricultural area under organic farming contract	The area of agricultural land for which the farmer has entered into a contract of organic farming	ha	P	F/L	SAFE
Stock of qualitative habitat function	Functional quality of habitats is maintained/increased	Density of Linear Landscape Elements	The total length of linear landscape elements within a landscape surrounding the farm	$m.ha^{-1}$	F / L	F/L	SAFE
		Connectivity index (γ-index) of LLE network	The connectedness of the nodes and segments in percent of the linear landscape elements network.	no unit	F / L	F/L	SAFE
ECONOMIC PILLAR							
VIABILITY							
Economic function	Farm income is ensured	Family farm income/ family work units/year	This value is revenues minus costs (own labour costs excluded)	$€.VAK^{-1}.yr^{-1}$	F	F	EU
	Dependency on direct and indirect subsidies is minimised	% of real net farm income from all subsidies	This indicator gives the part of the real net farm income coming from all subsidies	%	F	F	EU
	Dependency on external finance is optimal	Solvency = own capital/total capital	This indicator gives the part of the total capital that is owned by the farmer	%	F	F	SAFE
	Agricultural activities are economically efficient	Total output from total input (total factor productivity)	This value is the euro obtained from the production process per euro, from any source, introduced into the system	% (€)	F	F	EU
		Value added/work units = labor productivity	/	$€.unit^{-1}$	F	F	T & C, MAFF
	Agricultural activities are technically efficient	Total output from total input	This indicator is the number of J obtained from the production process per J, from any source, introduced into the system.	% (J)	F	F	EC, MAFF
	Market activities are optimal	Diversity of agricultural income sources, production as well as non-production	Gives the number of agricultural income sources, production (e.g milk, sugar beet) as well as non-production (e.g. agritourism, contract work), NOT non-agricultural income sources	n°	F	F	T & C
	Farmer's professional training is optimal	Years of professional experience	Gives the number the farmer has professional experience with the farming business. It does not hold into account the years the farmer was helping his parents on the farm.	years	F	F	SAFE
	Inter-generational continuation of farming activity is ensured	Existence of a new generation willing to take over the exploitation	Expresses if the farmer knows there is someone who is willing to take over the farm.	Scale (yes, ?, no)	F	F	SAFE
	Land tenure arrangements are optimal	/	/	/	/	/	/
	Adaptability of the farm is sufficient	Index of farm adaptability	State whether farm has unsolvable problems for: meeting institutional restrictions (Laws, regulations, standards…); and/or for effective land supply; and/or for effective labor/service supply; and/or for effective manager supply; and/or for effective funding of activities; and/or for effective input supply; and/or for effective know-how & innovation supply; and/or for effective output marketing	no unit (0 or 1)	F	F	SAFE
SOCIAL PILLAR							
FOOD SECURITY & SAFETY							
Production function of the agro-ecosystem	Production capacity is compatible with society's demand for food	Consumption/production	Gives for the major agricultural products the ratio of amount of consumption over the amount of production, in one country.	%	L	Land	Land
	Diversity of food and raw materials is maintained/increased	diversity of main food types	Diversity of main food types exported of the farm (by 'main' are excluded all on-site transformed food products and all secondary production (straw, greens...) / by 'food' is meant food potentially eaten by humans	n°	F	F	Land
	Quality of food and raw materials is maintained/increased	/	/	/	/	/	/
	Adequate amount of agricultural land is maintained	/	/	/	/	/	/
QUALITY OF LIFE							
Physical well-being of the farming community function	Labour conditions are optimal	Hours per year for farm labour	Gives the hours per year for farm labour by the farmer and his family.	hours	F	F	SAFE
	Health of the farming community is acceptable	Days of working incapacity	Gives the number of days in year the farmer is incapable to work	$days.\ yr^{-1}$	F	F	SAFE
Psychological well-being of the farming community function	Education of farmers and farm workers is optimal	Extra courses	Expresses if the farmer does extra courses.	binary (yes, no)	F	F	SAFE
	Family situation, including equality in the man-woman relation is acceptable	Equality man-women status	On the basis of the respective role of the man and the woman in farming activities (type and amount of work) and extra-agricultural professional activities (type and amount of work), expresses the man/woman equality ratio	binary (yes, no)	F	F	SAFE
	Family access to and use of social infrastructures and services is acceptable	Distance to administration services	Trivial	km	F	F	SAFE
	Family integration in the local and agricultural society is acceptable	Membership to non-agricultural organisations	Trivial	binary (yes, no)	F	F	SAFE
	Farmer's feeling of independence is satisfactory	Farmer' s feeling of independence of subsidies	Expresses how independent (on a scale from 1 to 5) the farmer feels towards subsidies	scale 1-5	F	F	SAFE
		Farmer' s feeling of independence of contracts	Expresses how independent (on a scale from 1 to 5) the farmer feels towards contracts	scale 1-5	F	F	SAFE
SOCIAL ACCEPTABILITY							
Well-being of the society function	Amenities are maintained/increased	Amenities	/	/	/	/	/
	Pollution levels are reduced	Noise effect	Shows if the farmer holds noise to the environment and neighbours into account, and acts upon this.	Binary (yes/no)	F	F	/
	Production methods are acceptable	Livestock welfare	Expresses the livestock welfare level by integrating 3 factors: 1) freedom to move: animals are not attached 2) access to an outside surface and are possibility to graze when the physiological state, climatic and ground conditions allow it 3) stables surface	scale [0, 1, 2 → 3]	F	F	SAFE
	Quality and taste of food is maintained or increased	/	/	/	/	/	SAFE
	Equity is maintained/increased	Ratio income received by the highest earning 20% and the lowest earning 20%	Trivial	%	R	R	/
	Stakeholder involvement is maintained/increased	Open houses	Expresses if the farmer does open houses	Binary (yes, no)	F	F	EC
CULTURAL ACCEPTABILITY							
Information function	Educational and scientific value features are maintained/increased	Open houses	Expresses if the farmer does open houses	Binary (yes, no)	F	F	SAFE
	Cultural and spiritual heritage value features are maintained/increased	/	/	/	/		

Legend. E = ecosystem / P = parcel / F = farm / L = landscapte / R = region / T = transect / W = watershed / C = crop / Catch = catchment / CP = cropping plan (all fields)

Appendix 4. The operationalization of sustainable wine production in this research. *The found indicators and measurements are marked by numbers from 1 to 9, corresponding to the following studies: 1: Slaper & Hall, 2011. 2: Pizzigallo et al., 2008. 3: Pattara et al., 2012. 4: Comandaru et al., 2012. 5: Point et al., 2012. 6: Neto et al., 2013. 7: Mascarenhas et al., 2010. 8: Pullman et al., 2010. 9: Jones & Alves, 2011.*

Dimension	Indicator	Measurement	Unit
People (Social)	Safety and security [1]	Crime statistics [1, 7]	Register crime per category (% per capita)
		Enhanced worker safety programs [8]	Capital spent on safety programs
	Educational attainment [1, 7, 9]	Degree attainment levels [1] by age group [7]	% per capita
	Quality of life [1]	Home ownership [1]	% per capita
		Poverty [1, 7]	% per capita below poverty limit
			% people benefiting from social insertion wage.
	Gender equality	Gender equality	% female – male workers
	Local support [8]	Local purchases [8]	% of procurement
		Local hiring [8]	% of procurement
		Supporting local community events [8]	Variations in Euro per year
	Human health [1, 4]	Birth mortality rate [1]	% per capita
		Lead in blood level [1]	% per capita
		Access to healthcare [7]	Medical staff per capita/average
			waiting time for surgery (months)
		Quality of water for human consumption [7]	Water samples not meeting national standard (%)
Planet (Environmental)	Waste [1, 3, 5, 7]	Trends in recycling, reuse and yard waste [1]	% glass recycling/ reuse [2, 3]
			% cork closure reuse [3]
		Waste production [5, 7, 8]	Tonnes, % of each type
	Energy [1, 2, 3, 4, 5, 6, 7, 8]	Electricity consumption [1, 2, 3, 5]	J/year/ha.
		Natural gas consumption [1]	J/year/ha.
		Alternative fuel consumption [1]	J/year/ha.
		Diesel & lubricants consumption [2, 3, 5]	J/year/ha.
		LPG use for bottle sterilization [6]	J/product
		Fertilizer use [2, 5]	Nitrogen fertilizer t/year/ha.
			Phosphate fertilizers

			t/year/ha.
			Potash fertilizers t/year/ha.
	Water [1, 4, 5, 6, 7, 9]	Water consumption [1, 2, 4, 7]	Liter per year per ha.
			Irrigation management [9]
		Eutrophication/acidification [4, 6]	Kg PO_4^{3-} eq
	Air quality [1, 6]	Toxic release inventory [1]	Kg of toxic per ha per year
		Number of air pollution ozone action days [1, 5]	Number of days
	Biodiversity [6, 7]	Pesticides use [2, 5]	Liter per year per ha.
		Fertilizer use [2, 5]	Kg per year per ha.
		Public green space [7]	Area attributed for green space (m^2)
		Nature conservation and management actions [7]	Investment in Euro per year.
		Land use [7]	Area distribution of land cover classes (%) variation rate in %
	Soil [6]	Soil degradation [6, 9]	Structural support in the vineyards [9]
Profit (Economic)	Personal income [1]	Personal income per capita [1]	Euro per capita per year
	Unemployment [1, 7]	Unemployment rate [1, 7]	% by sex

Appendix 5. List of interviewees

Interviewee	Position	Company/institute	Interview location	Date
IV1	Postdoctoral researcher	UTAD	Vila Real	16-05-2016
IV2	Professor Environmental Engineering	University of Aveiro	Porto, FEUP	02-06-2016
IV3	Top manager	Sogrape Vinhos, S.A.	Porto, IVDP	03-06-2016
IV4	Research Fellowship	INEGI	Porto, INEGI	17-06-2016
IV5	Project Manager	INEGI	Porto, INEGI	17-06-2016
IV6	Administrator	Duorum Vinhos	Porto, Foz	15-07-2016
IV7	Program Director	CSWA	Skype	10-08-2016
IV8	Viticulturist	Muxagat Vinhos	Vila Nova de Foz Côa	12-08-2016
IV9	Viticulturist	Ramos Pinto	Vila Nova de Foz Côa	12-08-2016
IV10	Technical & Certification Director	IVDP	Porto, IVDP	16-08-2016
IV11	Sustainability Manager	WASP5	Skype	16-08-2016
IV12	Viticultural Manager	Quinta dos Murças	Covelinhas	26-08-2016
IV13	Senior Government Official	IVDP	Porto, IVDP	31-08-2016
IV14	Consultant & Co-Owner	Inkwell Wines	E-mail	22-08-2016
IV15	Coordinator of the Knowledge Center	IVDP	E-mail	13-09-2016

Appendix 6. RSIS actors of the case-study region

The Porto and Douro wine innovation system is characterized by the following actors:

Abbreviation: **OIV**
Name: The international Organisation of Vine and Wine
Mission: ''The OIV is an intergovernmental organisation of a scientific and technical nature of recognised competence for its works concerning vines, wine, wine-based beverages, table grapes, raisins and other vine-based products.''
Level: Global
Website: http://www.oiv.int/

Abbreviation: **IOBC**
Name: The International Organisation for Biological and Integrated Control
Mission: ''The IOBC fosters research and practical application, organises meetings, symposia, offers training and information, especially of biological methods of control, but also of all methods, including chemicals, within an integrated pest management context. Major activities include development and standardisation of testing methods for effects of pesticides on beneficial species, pest and disease damage assessment, modelling in relation to pest and disease management, and the practical implementation of biological and integrated controls for pests and diseases of particular crops.''
Level: Global
Website: http://www.iobc-global.org/

Abbreviation: **CEEV**
Name: Comité Européen des Entreprinses Vins
Mission: The representative professional body of the EU industry and trade in Wines.
''The CEEV aims at promoting social, economic and legal environment that favours the sustainable and responsible development of a competitive EU Wine sector, and enhance the legitimate place of Wine and its culture, in Europe and in the world.''
Level: European
Website: http://www.ceev.eu/

Abbreviation: **IVV**
Name: Instituto da Vinha e do Vinho
Mission: ''Currently, the mission of the Institute of Vine and Wine, IP, is to coordinate and control the institutional organization of the wine sector, audit quality certification system, track the European's policy and prepare the rules for its implementation, as well as participate in the coordination and supervision of the promotion of wine products and ensure the functioning of the National International Vine and Wine Organisation Committee (CNOIV).''
Level: Portugal
Website: http://www.ivv.min-agricultura.pt/np4/home.html

Abbreviation: **IVDP**
Name: Instituto dos Vinhos do Douro e Porto
Mission: **''**The mission of IVDP, I.P. is to promote the control of the quality and quantity of Port wines, regulating the production process, and the defence and protection of the Douro and Port denominations of origin and the geographical indication of the Douro Region. ''
Level: Mainly Porto & Douro, also the rest of Portugal (IV10)

Website: https://www.ivdp.pt/index.asp?idioma=1&

Abbreviation: **AEVP**
Name: Associação das Empresas de Vinho do Porto
Mission: **''**The main puropose of AEVP, enshrined statutorily, is to ''represent and protect the interests of its Members and to promote and defend of Industry and Trade of Port and Douro wines and other wine products of the Douro Demarcated Region.''
Level: Porto and Douro
Website: http://www.aevp.pt/Default

Abbreviation: **AJAP**
Name: Associação de Jovens Agricultores de Portugal
Mission: **''**Today AJAP as an organization of farmers is convinced on the need for change and innovation to be introduced on farms and agricultural enterprises. This is also changing with a view to be increasingly closer to farmers and able to respond to their problems and desires, chore is right with few resources but possible because we still believe in the Young Farmers and the Portuguese Farmers.''
Level: Portugal
Website: http://ajap.pt/

Abbreviation: **ADVID**
Name: Associação para o Desenvolvimento da Viticultura Duriense
Douro Wine Region Cluster
Mission: ''Promoting the Sustainable Development of the Viticulture of the Douro Region''
''Contributing to the modernisation of viticulture and, consequently, to the increased profitability of vineyards in the Demarcated Douro Region and to the improved quality of its wines through promotional activities and the implementation and support of related studies.''
Level: Portugal
Website: http://www.advid.pt/home&codIdioma=2

Abbreviation: **PORVID**
Name: Associação Portuguesa para a Diversidade da Videira
Mission: Protecting the genetic diversity of the vines.
Level: Portugal
Website: https://www.isa.utl.pt/home/node/3636

Abbreviation: **INEGI**
Name: Institute of Science and Innovation in Mechanica land Industrial Engineering
Mission: ''INEGI is a Research and Technology Organization (RTO), bridging the University – Industry gap and focused on applied Research and Development, Innovation and Technology Transfer activities for the industry.''
Level: Portugal
Website: http://www.inegi.pt/inicial.asp?k=z&LN=EN

Appendix 7: List of NVivo coding categories

1. Actors & networks
2. Demand
3. Douro sustainability programme
4. Entrepreneurship
5. Finance
6. Financing infrastructures
7. Innovation system
8. Institutional framework
9. Institutions
10. Knowledge domains, learning processes & logistics
11. Learning and Innovation
12. New World wine regions
13. Other hindering factors
14. Quotes
15. Sustainability - environmental
16. Sustainability - financial
17. Sustainability - future projections
18. Sustainability - genetic erosion
19. Sustainability - herbicides-funghicides-pesticides
20. Sustainability - labels
21. Sustainability - organic
22. Sustainability - perception
23. Sustainability - social

The full transcripts of the interviews and the NVivo 11 data file are available on request.

Appendix 8. Benefício: parameters for evaluating vineyards

Data retrieved from Paulo Martins, 2011.

Criteria	Score Minimum	Score Maximum
SOIL AND CLIMATE		
Location	-50	600
Altitude	-900	240
Slope	1	101
Substratum (nature of the land)	-400	100
Gross elements (stoniness)	0	80
Exposure	-30	100
Shelter	0	60
VITICULTURAL		
Yield (productivity)	-900	120
Vines (varietals)	-300	420
Planting (density)	-50	50
Training of vines (system)	-500	100
Age of vineyard	0	60

Once all scores are added up, the vineyard is classified according to the following scale:

Classification of vineyards according to total score	
Class	**Score**
A	More than 1200 points
B	Between 1001 and 1200 points
C	Between 801 and 1000 points
D	Between 601 and 800 points
E	Between 401 and 600 points
F	Between 201 and 400 points