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Suggestions for the development of a quantitative framework of Terroir Analysis in Swedish Vineyards

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Underlag för framtagande av ett kvantitativt ramverk för terroir analys på svenska vingårdar

Bachelor degree thesis, 15 credits in Physical Geography and Ecosystem Analysis

Department of Physical Geography and Ecosystem Science, Lund University

Level: Bachelor of Science (BSc)

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Suggestions for the development of a quantitative framework of Terroir Analysis in Swedish Vineyards

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Bachelor thesis, 15 credits in Physical Geography and Ecosystem Analysis

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1 Abstract

Wine is an important cultural crop and is grown in vineyards that sometimes claim to have a unique ”terroir” - a specific taste and character based on their physical attributes and location. Regulations and previously published work are not easily available, into how to measure and assess this terroir. It is important for countries such as Sweden to have a terroir assessment system, which would enable them to sell ”quality” wine under EU law. To provide a possible solution for this, literature was reviewed and a framework found and developed for use in vineyard quality assessment. The framework involves 3 categories (Geology, Terrain and Climate) and 12 sub-parameters, that assess different elements of a vineyards location, with each element given a score of good, intermediate or bad. These scores are then statistically analysed, to give a final score using a choice of 7 different weighting options. These different options allow various focuses of viticulture to be expressed. The framework was test run using Kullabergs Vingård in Skåne, Sweden as an example, both in a spatial (regional differences) and temporal (climatic change) context. This framework is expected to provide, an easy to use but in depth suggestion for terroir analysis, which is especially useful for the wine industry in Sweden.

2 Introduction

2.1 Wine

Wine has been a source of connection and great joy for a large proportion of humanity for generations. In fact, it is an essential part of religious, cultural and social life for many. Ranging from those who practice Judaism and Christianity (with their wine based prayers), to the Romans and their belief that wine was a daily necessity. However, what constitutes a good wine, is and always has been, a subject of contention. An additional source of contention, surrounds the premise that great wine is grown, not made (Nicholas 2015). While this may sound obvious, the idea of the importance of winegrowing (the practice of vineyard cultivation in order to grow grapes) outweighing the importance of winemaking (the process of wine production from grown grapes), discussed in depth in the ”Science of Wine” (Goode 2005), has not always been accepted, but is essential in the foundation of this article. Winemakers in France are referred to as ”vignerons” - literally meaning wine grower, and this paper will follow that line of thought, by looking at wine as a product of its growth from seed to bottle, and not as a product of a wine making process from ripe grape to bottle.

So what is wine and how is it produced? Wine is defined by the Oxford Dictionary as ”an alcoholic drink made from the juice of grapes that has been left to ferment” (this is of course only relevant for grape wine, other types of wine are made of various ingredients including honey, elderberry and other fruits - they are beyond the scope of this article). The grapes used to make wine, are generally varieties of the European species *Vitis vinifera*, but attempts have been made to use other species of grape. Some of these species from the Americas have natural defence systems against a pest called Phylloxera and have been used successfully as a rootstock for grafted *Vitis vinifera* (Gale 2011). However on their own, the quality of the wine produced is not high enough to compete with the classic European outcomes. For the purposes of this thesis, wine growing will be used to refer to those who grow and produce wine from different varieties of *Vitis vinifera*.

2.2 Wine Classification and Terroir

2.2.1 The old world vs the new

Once wine is produced, comes the task of defining it and its quality. There are two traditional ways of defining wine and they split between the "old world" (mostly referring to European wine countries) and the "new world" (the rest of the world but most importantly the USA, Australia, South Africa and New Zealand). Old world definitions, mostly rely on the specific area, grower and producer to give a sense of the quality of the wine, whereas new world definitions try to give more of a sense of the variety of grape used and in what quantities (Unwin 2012). Neither of these methods are right or wrong and in the world of wine rating the arguments continue as to what is more useful. This thesis will focus on delving into the importance of geographical characteristics for wine quality, as even those that use grape variety as the most important component of wine rating, do so with the utmost respect for geographical factors.

In the world of education there is the concept of "sense of place" (Shamai 1991), that attributes specific characteristics and feelings to certain locations. This has been widened to allow for a "taste of place" (Trubek 2008), meaning that foods grown and produced in a certain area will have unique characteristics. This is one of the reasons why the production of certain foods is limited to specific areas by the European Union, amongst others. For example, the European Council regulation Number 510/2006, limits the production of the Cornish Pasty to the region of Cornwall, United Kingdom. This is a view that geographical locations convey unique characteristics to certain foods and therefore must be safeguarded. Part of this thesis will try to challenge this point and delve into whether geographical locations really do have such a measurable impact on foods.

2.2.2 Terroir

If it is established, that the character of a geographical space can be conveyed in the taste of its products, this should be valid for wine too. In fact, descriptions referring to location are often heard in the wine trade. However, it is of paramount importance to understand if these characteristics are due to simple regional differences in growing procedures or something deeper that can possibly be called "terroir" (Goode 2005). To give credence to the idea that location affects quality and taste, there needs to be a clear understanding of why, and what processes are involved. The French word "terroir" translated as "pertaining to the soil", is often used in conjunction with wine making and has been defined for the wine industry by the OIV (International Organisation of Vine and Wine) resolution that states: *"Terroir" includes specific soil, topography, climate, landscape characteristics and biodiversity features"*. The idea of each growing location having unique characteristics, or in other words a unique terroir, is the main basis for the oldest of wine rating systems (the French AOC - Appellation d'Origine Contrôlée), showing that the characteristics of a wine growing location can contribute to the character and the quality of the produced wine. However, it is difficult to define and study terroir on a scientific basis, (Van Leeuwen and Sequin 2006) because a consensus over what constitutes terroir and how to measure it, is almost impossible to find.

2.2.3 Terroir Components

So what should terroir comprise of? To give some examples of the conflict surrounding this, there are those that believe in geological factors being the most important factors in predicting the outcome of the wine and thus the highest weighted aspects in deciding a wine growing location (Wilson 1998) (Pomerol 1995). However, other scientists believe that the most important component is climate, without the correct weather context, the quality of the wine produced can never go beyond a certain level (Jones 2014). Additionally, there are others that believe in a blended hierarchy of factors, with wine variety being the most important, followed by climate and finally geological factors (Rankine et al. 2017). Other scientists, believe in water stress and nutrient availability as the most important factors predicting wine success (Busacca and Meinert 2003). The following thesis, will attempt to cater to these differing viewpoints, when discussing and rating the components of terroir.

2.3 Terroir Frameworks

As this article will require a working and scientific definition of terroir, it will have to start by going back to basics. To narrow down the room for error, the first step will be to use the Oxford Dictionary definition of terroir which states: "The complete natural environment in which a particular wine is produced, including factors such as the soil, topography, and climate". To repeat this in simple words - the terroir of a location includes what is below the ground, on the surface and above it. As mentioned earlier, there are large variations of opinion, in how and if it is even possible to measure this terroir. Therefore, in order to use a terroir measurement framework, the following conditions need to be satisfied:

- Is this terroir measurement repeatable and reusable by others?
- Is this terroir measurement based on objective science or is it subjective?
- Does this terroir measurement have backing in previously published and verified scientific work?.

2.3.1 Existing Terroir Frameworks

Within the European Union, there are two main types of wine - "quality" and "table" wine. For a wine to be labelled and sold as "quality" wine, it must be either rated as PDO or PGI. These are defined as follows: *Protected designation of origin (PDO) designates the name of a product which must be produced within a determined geographical area using recognised and recorded know-how. All products with PDO status must be produced exclusively with grapes from the area in question. Protected geographical indication (PGI) designates a product with a quality, reputation or other specic features that can be attributed to a determined geographical area. All products with PGI status must be produced with at least 85 percent of the grapes coming from the area in question.* (Source: Eurostat, October 2017). Each country that produces these quality wines must have a system for rating them.

Some of the systems that exist for rating wine are very well known. The French AOC (Appelation Origin Controlee) is possibly the most famous, with the Italian DOC (Denominazione di Origine Controllata) and Spanish DOP (Denominación de Origen Protegida) not far behind. These systems are generally based on spatial characteristics (i.e. location dependent) and can be considered basic terroir measurement frameworks - as they rate a wine based on its growing location. Additionally, there are an endless amount of rating systems that use public opinion to rate produced wines themselves.

When looking at these existing frameworks, some are based on the wine output itself, using a sensory based test such as the one used in the French AOC system, whereby the taste of the wine is what gives clues to its terroir - every location is deemed to have a specific taste and the wine produced is tasted and compared to the standard, however the tasting is arbitrary and can be done by local (possibly biased) testers (Joseph 2006). The Spanish system relies to a large extent on differentiating between local wine making and styles, quoted as *"qualities and characteristics due to geographical origin, with human and cultural factors involved"* (Vidal et al. 2013), with the Italian system concentrating on promoting historical and local varieties of grapes (D'Agata 2014). However enjoyable these type of terroir framework would have been to develop, they were ruled out due to them not being repeatable in a quantitative context by other non-local actors. When rules are convoluted and there are unclear, non-quantifiable indices to test (such as an arbitrary requirement for taste) - it is very difficult to justify using these terroir frameworks in a different context to the one they were developed for.

Worldwide, there are systems that are very deliberately geographical, one of them being the American AVA method of defining wine strictly by its growing location notwithstanding any other factors, unfortunately this doesn't provide any understanding of the quality involved. The system rather, heavily defines the geographical pockets that grow wine, stating simply that they will all grow different products (Source: Alcohol and Tobacco Tax and Trade Bureau).

Since the wine industry definitions of terroir seem quite subjective, qualitative and non-repeatable, it was deemed necessary to follow the quantitative route into non-sensory systems. In the available literature there is some agreement as to what parameters should be present for a correct framework - for climate factors, there is a general acceptance of a heat sum index and precipitation indices being important (Goode 2005), but there is no clear research into a repeatable framework that is acceptable in all wine regions. Assessing all the options, narrowed down the possibilities to previously studied frameworks, that point to the categories and sub-parameters necessary, for giving a quantitative, controlled insight into vineyard location quality, but not actually how these should be measured. Therefore, the focus of this thesis, has been to investigate each of these sub-parameters and define the correct indices for running a vineyard quality framework, that can provide a description and a numerical score for a vineyards terroir. Different options for the statistical analysis of this numerical score will be presented.

2.4 Sweden and Wine

To narrow down the area where the developed terroir framework would be tested, an exciting possibility would be within the Scandinavian context and more specifically Sweden. Sweden is established as a wine country with EU backing but has less than 500 hectares of vineyards (Source: Eurostat, October 2017). However, since grapes are a new crop in Sweden, there is not so much cultural knowledge or an accepted quality rating system. This has the effect of not allowing Sweden to sell "quality" wines for higher prices and minimises the profit the winemakers can make. To this end, there are those scientists, who are looking into establishing a sustainable terroir framework for Scandinavia, by looking at the taste and sensory attributes of Scandinavian wine, this is entitled as the Nordic Light Terroir project (Nordmark et al. 2016). As this is a sensory based project, it has a different aim than this paper, however, the idea of setting up a developed framework for use in Scandinavia is a tempting prospect, as nothing to compare with that exists at the present moment.

Anecdotal evidence by Swedish wine growers (Crouch 2015) and literature studies, show that growing wine in Sweden, which is something that has not been of great value in the past will become a better prospect with climate change (Jones and Schultz 2016). This supposition is based on higher temperatures providing better conditions for grape maturation and alcohol content. However, this is not something that can be relied upon to happen (extreme heat can have the opposite effect on wine growing) or if it will happen, it cannot be relied on to occur gradually (Nicholas 2015). Therefore, hoping that climate change will turn Sweden into the next perfect country for wine growing maybe a bit misguided. Notwithstanding that, it is very important that the developed terroir framework will be able to take into account climatic changes and their possible effects on terroir results. There are some who criticise the obsession with wine production when agriculture overall is being fundamentally challenged due to climate change. (Nicholas 2015) argues however, that although perhaps not the most important concept to be concerned about, as a cultural crop and mainstay of many lives and practices, wine production in a changed climate is still very important to study and devote resources to.

2.5 Kullabergs Vingård

For the purpose of illustrating the developed terroir framework in practice, this thesis will focus on an example of Swedish viticulture. Kullabergs Vingård is a vineyard situated at a latitude of 56.3N, a longitude of 12.5E and an altitude of 40 meters above sea level, north of Helsingborg, close to the Kullaberg peninsula in the region of Skåne, South Sweden. It has been growing wine in two separate fields under the present team for 4 years and aims to use a scientifically based, locally focused system to grow Swedish grapes and produce Swedish wine.

2.6 Aim

The forthcoming thesis will suggest a defined quantitative framework, that can be used to measure and describe the terroir of a specific vineyard. To assess the viability of the framework - the vineyard at Kullaberg will be used as a working example both in the current perspective and in the context of climatic change.

3 Methods

When discussing the technical details of measuring the terroir of a specific area or region, one must establish a clear methodology based on quantifiable, repeatable parameters. The issue with this, is that as mentioned previously, there are no repeatable, scientifically based frameworks to define the terroir of a location. To further hone this measurement of terroir, it was decided to develop a framework, based on widely agreed parameters from within the literature available. Originally, there was an attempt to create a framework based on anecdotal evidence from within the wine industry, however this was deemed to be too loose scientifically and suffered from being non-subjective, to the point where crushing rocks into powder and adding this to the wine, was recommended as a measure of improving terroir. Therefore, the best option was to find a framework that has been used in the past but to research and find new indices for every sub-parameter within the framework. In this case, terroir will be looked at using a framework based on parameters drawn from a conference proceeding by (Itami et al. 2000). These parameters are used as the most all encompassing set of requirements found for wine grape growing, and are less subjective than other sensory or non sensory terroir assessments. While this is originally used as a pure measure of vineyard quality, this paper will argue that terroir can be rated and described using this framework.

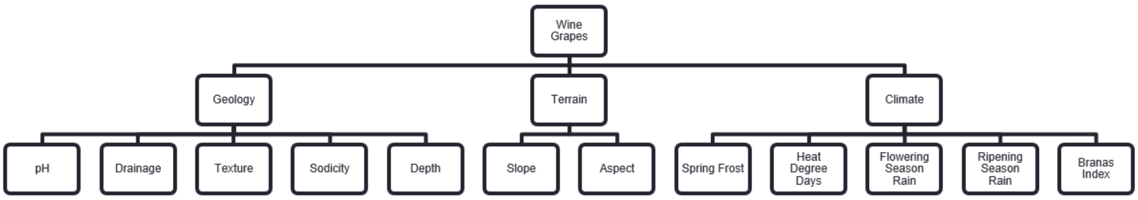

Figure 1: The original framework redrawn from (Itami et al. 2000), showing categories and sub parameters of vineyard quality

The Itami framework (see figure 1), provides a division into three main categories of vineyard quality - used here for terroir (climate, terrain and geology) and into sub-parameters. The problem is, how to define and evaluate these sub-parameters and to ask what indices exist that can be used to assess them. Therefore, it was decided to undertake a literature review and create a scale for these sub-parameters, by giving each of them a numerical grading to give a statistical outcome of where to establish a high scoring vineyard. These sub-parameters will be defined further in this paper and weighted in 7 different scenarios to give a choice of scores based on different focuses of terroir. Every sub-parameter will be assigned 3 possible values, with 1 being a bad score, 2 an intermediate score and 3 a good score. The next sections will detail the indices defined through research, for each of the sub-parameters and the details of the possible scores.

3.1 Climate

Overall, climate for growing wine grapes is based on temperature, precipitation and humidity. Conventional wisdom has it, that there should be a polar limit of 50°N or 45°S (Fitzharris and Enducher 1996) for wine growth. This would on first glance bode badly for Scandinavia (with the most southerly tip of Sweden at 55N) however maritime balancing may be of help. Maritime balancing, refers to the fact that locations close to the sea such as Kullaberg, will involve increased humidity and less extreme ranges of temperature, when compared to similar areas further inland (Moulton and King 2001).

3.1.1 Spring Frost

The first sub-parameter of climate is frost kill, and the question here, is to establish what level of frost will hurt vines and when. One possibility would be, to define the suitability of a vineyard based on the date of the year when there is the final spring frost, however this runs the risk of the growing season just being extended into the autumn. Therefore, an objective index for frost effect on vines is to look at the total length of the frost free growing period (number of days between the last spring frost and the first autumn frost). Based on research by (Fitzharris and Enducher 1996), an index for testing this parameter could be the requirement of a frost free growing period of 180 days minimum. As to the question of what specific level of frost is required for vine damage - there are those that put this as between -1.5°C and -2°C (for dry and cold conditions), however, since a temperature of -0.5°C will kill grapevines when they are wet, this will be used as the critical level for this sub-parameter (Wang et al. 2018).

Scoring: A score of 1,2 or 3 was defined as: Below 180 days of frost free growing period as bad [1], between 180 and 200 as intermediate [2] and above 200 as good [3].

3.1.2 HDD - Heat Degree Days

There are various options to look at, for defining heat sums or heat degree days. These constitute a way to look at the cumulative temperature within a specific area, and not on vague measurements such as average temperature alone. Each species of plant has a different threshold, beyond which it is considered, that the heat sum is sufficient for good growth of the specific species. To calculate the specific heat sum for growing *Vitis vinifera*, common indices used by the wine industry include the Winkler Index (used more often in the United States). However, this index does not allow its calculation to be adjusted for different latitudes, which is important when there are more sunlight hours per day in a country such as Sweden (during the summer), than there is in lower latitude locations such as France or California.

Consequently, it was decided to use the Huglin heat sum index which was developed by Pierre Huglin and follows the below formula (see figure 2). The equation involves the average temperature (T) and the maximum temperature (Tmax) per day, summed up for the period between the first of April and the end of September (Huglin 1978). Additional calculations follow the formula, and involve multiplication by "d" which is the latitude factor (allowing for the extra solar radiation time existing during the longer days in the Northern latitudes). Based on work by (Tonietto and Carbonneau 2004) the latitude factor was calculated for this paper as 1.09. This was based on the percentage increase in daylight length from 45 - 50 degrees north to 50 - 55 degrees north being calculated as 132 percent, correspondingly, the latitude factor was incrementally increased by 132 percent to 1.09. The actual result for the sum according to Huglin would be best between 2100 and 3000, with results below and above this level, limiting the types of grapes being possible for cultivation. For the purposes of this model, the index was fitted to the Swedish context with the correct latitude factor and possible scores divided into categories.

Scoring: A score of 1,2 or 3 was defined as: Below 1500 as cold and therefore bad [1], 1500-2100 as cool and therefore intermediate [2] and above 2100 with a top limit of 3000 as good [3] (Tonietto 1999).

$$\sum_{\text{Apr}}^{\text{Sep}} \frac{(T-10)+(T_{\text{max}}-10)}{2}\, d$$

Figure 2: Standard Huglin Index formula

3.1.3 Flowering Season Rain

Moving onto precipitation for vineyards, and the limitations are of a different kind than with temperature. Annual precipitation of over 450mm is a prerequisite for any grape growing, however an excess of water is not considered ideal (Jones 2015). This is in order to provide some stress for the vines, without which, the excess energy within the plant would go to the roots, rather than the fruit. This is an evolutionary phenomenon, which allocates appropriate energy for best survival of the species. If a plant is under some water stress, it is appropriate for more energy to go into reproduction, hence into fruit production, which is what is wanted in vineyards. Within the flowering season - defined for the Swedish context as June and July, there is a requirement for a minimal amount of rain spread throughout this time frame rather than a lot at once (Fitzharris and Enducher 1996; Jones et al. 2012; Jones 2015). Therefore, a suitable index for this sub-parameter, would be to compare the daily rainfall within these months to the yearly average. Rain during these months would have to be below the average, to get an intermediate score and lower than 50 percent of the average to get a good score.

Scoring: A score of 1,2 or 3 was defined as: If daily average precipitation during June and July is above the yearly average score, this is defined as bad [1], below average daily rainfall (but above 50 percent of average) is classed as intermediate [2] and below 50 percent of the average is good [3]. However, if yearly precipitation is below 450mm, no score above 1 can be achieved.

3.1.4 Ripening Season Rain

While a certain amount of rain is necessary throughout other parts of the season, as mentioned in the previous paragraph, during the time of ripening, defined as August, September and October, there is a clear and essential need for calm, sunny and dry conditions (Fitzharris and Enducher 1996; Jones et al. 2012; Jones 2015), where the ambition is for no rain whatsoever. A suitable index would be to use the same as the previous sub-parameter but for different months. Questions maybe raised as to the suitability of two separate sub-parameters with the same index, but as the months and seasons are different, the indices answer two different questions.

Scoring: A score of 1,2 or 3 was defined as: If daily average precipitation during August, September and October is above the yearly average score, that is classed as bad [1], below average but above 50 percent of the average is classed as intermediate [2] and below 50 percent of the average is classed as good [3]. However if yearly precipitation is below 450mm no score above 1 can be achieved.

3.1.5 Branas Index

Aside from simple precipitation indices, there is an importance to look at the interplay of precipitation and temperature. As seen earlier with frost, cutoff points change when used in conjunction with other parameters. Therefore in order to understand humidity levels, an index was sought after and the Branas Hydrothermic Index (see figure 3) was found. While originally an index for mildew (a fungus that affects vines amongst other plant species and even humans), it can also be used to assess overall levels of harmful humidity for vineyards. It involves the sum of average temperatures per month, multiplied by total precipitation for that month, during the period first of April to the end of August. While there is an argument to using the end of September or even October as the date for the end of the growing season in Sweden, the date was left as is, in order to be able to compare with other geographical points. The outcome of the Branas Index is based on a sliding scale where the lower humidity the better the score. Research shows a critical level of 2500, below which the conditions for wine growth are good, with another critical level of 5100, above which the conditions are bad (Kose 2014).

Scoring: A score of 1,2 or 3 was defined as: A Branas index score [1] above 5100 is bad, 2500 to 5100 is classed as intermediate [2] and below 2500 as good [3].

$$\sum_{\text{Apr}}^{\text{Aug}} (T \times P)$$

Figure 3: Standard Branas Hydrothermic Index formula

3.2 Geology

The next section to be looked into, contains the sub-parameters that are relevant to what is below the ground. This is an area of study which is quite controversial, due to the almost endless conflict between wine experts as to how much of an effect the soil surrounding the vines has on the growth itself. An attempt here was made to discount anecdotal evidence and hearsay and to stick with a purely plant science based approach, to defining the content of the following sub-parameters.

3.2.1 Soil pH

The essence of the soil pH sub-parameter is to define a level of pH, that will enable the specific plant to most efficiently uptake the correct nutrients and cations. While most plants have an optimal pH level of up to 7 (slightly acidic to neutral), wine grapes prefer a slightly more acidic soil. They will grow with a soil pH of anywhere between 4 and 8.5, however a level between 6 and 6.5 will encourage maximum cation absorption and is considered to be best (Brown 2013).

Scoring: A score of 1, 2 or 3 was defined as: pH between 4 and 8.5 is bad [1], 5.5-7 is considered intermediate [2] and 6 - 6.5 is considered good [3].

3.2.2 Drainage

When looking at the makeup of the soil and its ability for water to drain, logic may dictate that the best situation for plants would be a balanced level of drainage, to maximise the rainfall and stop any possible water stress. However, as mentioned previously, good drainage that allows moderate water stress early in the season is important for wine growth, this is because plants under this stress will reassign energy to the fruit instead of roots and leaves, for reproductive reasons, giving the best possibilities for good grapes and hence good wine (Fitzharris and Enducher 1996; Jones et al. 2012; Jones 2015).

In order to achieve this good drainage, we need to establish and look at what parameters within soil can lead to good drainage. Unfortunately, it is not as simple as looking for the best type of soil for drainage, as wine grapes are grown and do very well on soil types all throughout the spectrum. So to narrow this down, an index was developed that follows the interactions between humus, clay and calcium carbonate percentages within the soil (as illustrated in figure 4). Decent drainage, relies on a good ratio of humus (organic matter) to clay, and sufficient calcium carbonate within the soil. These conditions come about because a large amount of clay leads to waterlogging in the soil and bad drainage, so an amount of well draining organic matter needs to exist. Additionally, the necessity of ample calcium carbonate (found in calcareous soils) is for flocculation ("binding together of particles") of the clay-humus complex (Seguin 1986; Berry 1990). To set a level of what soils can be considered calcareous, the FAO (Food and Agriculture Organization of the United Nations) definition, stating a lower limit of 15% calcium carbonate for soils to be considered calcareous, is used.

Scoring: A score of 1,2 or 3 was defined as: If the humus content is less than 10 percent of the clay content this is classed as bad [1], if both the humus content is above 10 percent of the clay content and the $CaCO_3$ content in the soil is above 15 percent this is classed as good [3], however, if the $CaCO_3$ content in the soil is below 15 percent, this is classed as intermediate [2].

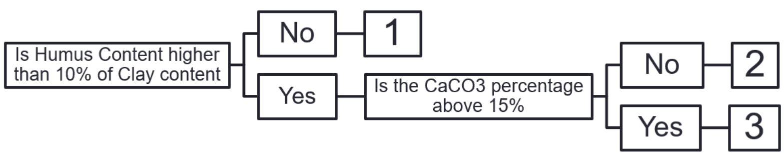

Figure 4: The flow chart for the drainage sub-parameter

3.2.3 Texture

Soils producing good wine all over the world have extremely varying soil textures, with winegrowers in Swartland, South Africa being very proud of their sandy soils and the winegrowers of California extolling the virtues of their loamy soils. There is currently no soil texture index that can be defined as having the correct spectrum for wine grapes. However, one that can be used is the humus content within the soil - similar to the previous drainage index. Humus content, shows the level of organic matter within the soil, with research showing the best level of humus (for soil texture) to be between 2 and 3 percent. Too little organic matter is bad for nutrient availability for the plants, however, a surplus of organic matter is also bad for a variety of reasons. Chiefly among them, in relation to wine growth is the need for some nutrient stress (as well as the water stress mentioned earlier) to increase energy being channelled towards the grapes (Winkler et al. 1974; Berry 1990).

Scoring: A score of 1,2 or 3 was defined as: humus is classed as good [3] when at a level of between 2-3 percent of the soil weight (for the first soil layer up to the appearance of bedrock), intermediate [2] at a a level above 3 percent and bad [1] at a level below 2 percent.

3.2.4 Sodicity

Sodicity, defined by the FAO as a high proportion of exchangeable sodium ions, relative to other cations and the cation exchange capacity. This can lead to very unstable soils due to sodium binding to soil particles. In the context of wine growth, soil instability is something to be very concerned about, with the drive to maintain good drainage. Unstable soils can lead to erosion, soil dispersal or blocking of soil pores to not allow water to flow through - sometimes leading to waterlogging in levels of the soil (Source: North Dakota State University). It is not enough just to look at the amount of sodium within soil on its own - it needs to be put in some sort of context. Therefore, the specific parameter needing to be looked at here is the ESP (exchangeable sodium percentage), which looks at the available sodium as a percentage of the CEC (cation exchange capacity). Research shows, that an increased ESP leads to depressed vine growth (higher levels leading to leaf burn - browning of the leaves), with the data showing that optimum exchangeable sodium for wine grapes is below 10% and certainly not higher than 15% (Khanduja 1980).

Scoring: A score of 1,2 or 3 was defined as: an ESP level above 15 percent is classed as bad [1], 10-15 percent is classed as intermediate [2] and below 10 percent is classed as good [3].

3.2.5 Depth

While it may be difficult to establish what would be the best depth for the soil and where to measure that from, research from the Mediterranean has shown, that when measuring soil depth up "until the appearance of bedrock or calcareous depositions", the depth is inversely correlated with grape quality. Meaning that the shallower the soil is, the greater increase in water stress and subsequent increased fruit resource allocation, which is great for good quality wine (Coipel et al. 2006). This was measured on a scale of 0.6 to over 1 metre below ground level and can be broken down to increments of 0.2 metres.

Scoring: A score of 1,2 or 3 was defined as: soil depth of 0.6-0.8 metres below ground to bedrock is considered shallow and good [3], more than 1m is considered deep and bad [1] therefore between 0.8m and 1m is considered intermediate [2].

3.3 Terrain

Finally, the terrain category is the one that looks at the surface of the ground and its geographical characteristics, namely the aspects of topography.

3.3.1 Slope

Since there are examples of wine grapes being grown on slopes of very different levels, maintaining a scientific rating for an ideal slope vector is a difficult task. The components that need to be balanced are, soil erosion potential (which increases with higher slopes), labour costs (also increases with higher slopes - as workers work slower) and ease of access (similar thought process as labour costs). These parameters push towards less steep slopes as being the best option, however with flatter surfaces there is less drainage (a problem as mentioned previously) and a possible issue of temperature exchange (whereby cold or hot weather can get ”stuck” in dips in the land, whereas steeper gradients allow better temperature exchange). Therefore, the correct gradient index would cater for all of these aspects, with research showing a best gradient value to be between 3 and 15 percent (MacGregor 2016).

Scoring: A score of 1,2 or 3 was defined as: A slope of over 15 percent gradient is classed as bad [1] and below 3 percent is classed as intermediate [2]. For a slope to be classed as good [3] it should be between 3 and 15 percent.

3.3.2 Aspect

When looking at how to define the perfect aspect of a vineyard, the main aim for this sub-parameter is to heighten solar catchment (i.e. the range of available sunlight that can be accessed by the vines). Since this framework is aimed at being used in the Northern Hemisphere, a southerly aspect can be considered to be optimal. This means quite simply, that vines open for solar catchment to the south, would be optimal for growth.

Scoring: A score of 1,2 or 3 was defined as: solar catchment to the south is good [3], north is bad [1] and east, west is classed as intermediate [2]. This only applies if the catchment is open to this aspect, if for example, a large mountain or building is blocking the sunlight, the aspect is irrelevant and work must be done to establish the direction of available solar radiation.

After defining the indices that will be used to develop the scores for each of the sub-parameters within the framework, the next step is to assess how to statistically calculate the results themselves, i.e. how much weight to give to each section and subsection of the framework. The next section will deal with the different options for this issue.

3.4 Weighting & Scoring Options

As every sub-parameter in the framework now has a score of between 1 and 3, it maybe expected to call it a day and calculate a final score for the terroir of the vineyard. However, this would be unfair as some sub-parameters are more important than others to overall vineyard quality and terroir expression. Therefore, a system of weighting must be decided upon - and 7 different weighting options have been calculated for this framework (see Table 1). These different options involve dividing an overall score of 1 between all the different sub-parameters and categories.

The first option (titled as original weightings) is, to use the different weightings for the sub-parameters listed by Itami et al in the original framework that this thesis is based on. These weightings rank the sub-parameters in order of importance for GIS placement of vineyards, and are an option with the backing of previous work. Within this option there are three sub options that allow changes to be made to the weightings of the categories (geology, terrain and climate). These changes would be made following on from the different schools of thought within terroir (as mentioned in the introduction). Namely, whether climatic or geological factors are the most important facets of terroir. One option, referred to as "Classic" is geology focused (a category score of 0.7 for geology, 0.1 for terrain and 0.2 for climate), one referred to as "Inverted" is climate focused (a category score of 0.2 for geology, 0.1 for terrain and 0.7 for climate) and one is considered "Equal Parts" (a category score of 0.45 for both geology and climate and 0.1 for terrain). None of these options increase the weighting of the terrain category, as no scientific backing can be found for terrain components having too much of an importance within terroir.

An additional way of assessing the scores (entitled non-original weightings), would be to allow the scores within the various categories to be completely equal to each other. This would mean that all the soil sub-parameters have the same value, all the climate sub-parameters have the same value and same with the terrain sub-parameters. This would contribute to the subsequent score being affected only by the category weighting and not the sub-parameter one. However, the 3 options for the weightings of the categories (classic, inverted and equal weights) remain, allowing the differences within terroir scientists to be seen (as to whether climate or geology should be more important).

The final and most simple option is to abolish all weightings and give every single sub-parameter across every category the same weighting within the model, giving every sub-parameter the weighting of 1/12 (a simple division from 1).

These options will allow bias to be removed from the framework, by looking at different scores with different weightings. The various weighting options are shown and described in table 1. Additional information on running the framework include; a division by 3 of the final score (as each sub-parameter gets a possible score of up to 3) which gives a number lower than 1 and the intent by the author for users of the framework to calculate 7 different scores (according to the different weighting options) and to take an average if needed. This will lead to simple final scoring possibilities that can be compared with other locations.

Table 1: The table of various weightings according to the different options, all weighting options must add up to 1

		Original Weightings			Non-Original Weightings			
					Sub-Parameters Equal			All Parameters Equal
Category	Sub-Parameter	Classic	Inverted	Equal Parts	Classic	Inverted	Equal Parts	
Geology	Ph	0.0658	0.0188	0.0423	0.14	0.04	0.09	1/12
	Drainage	0.1288	0.0368	0.0828	0.14	0.04	0.09	1/12
	Texture	0.0308	0.0088	0.0198	0.14	0.04	0.09	1/12
	Sodicity	0.1288	0.0368	0.0828	0.14	0.04	0.09	1/12
	Depth	0.3465	0.099	0.22275	0.14	0.04	0.09	1/12
Terrain	Slope	0.0857	0.0857	0.0857	0.05	0.05	0.05	1/12
	Aspect	0.0143	0.0143	0.0143	0.05	0.05	0.05	1/12
Climate	Spring Frost	0.0146	0.0511	0.03285	0.04	0.14	0.09	1/12
	HDD	0.0922	0.3227	0.20745	0.04	0.14	0.09	1/12
	Flowering Rain	0.0282	0.0987	0.06345	0.04	0.14	0.09	1/12
	Ripening Rain	0.0564	0.1974	0.1269	0.04	0.14	0.09	1/12
	Branas Index	0.0086	0.0301	0.01935	0.04	0.14	0.09	1/12

3.5 Sensitivity Analysis

After the framework and its possible weightings have been established - it is necessary to underline the most sensitive sub-parameters. This allows more of an understanding into why the framework behaves in the way it does and additionally, what winemakers can work on to "bump up" their terroir score. Since the sensitivity depends on the weighting system used, the following list shows the sub-parameters with a final weighting of over 10% of the final score (of 1) [these figures can also be seen in Table 1]:

- Depth, Drainage and Sodicity (within the original weightings classic option)
- HDD and Ripening Rain (within the original weightings inverted option)
- Depth, HDD and Ripening Rain (within the original weightings equal parts system).
- All of the Geology sub-parameters (within the non-original weightings, classic system)
- All of the Climate sub-parameters (within the non-original weightings, inverted system)

- Within the non-original weightings "equal parts" and "all parameters equal" systems, no sub-parameters are equal to more than 10 percent of the whole.

This list shows that the importance of the different sub-parameters, really depends on the weighting system used, which is the correct behaviour for a framework of this kind. The reason this is true, is because different weighting system possibilities allow different winemakers and scientists to use their own hierarchies of importance, but still follow a tried and tested method of vineyard statistical analysis.

3.6 Data Collection and Analysis

To test this framework, and run it in a living Scandinavian example, data was collected relevant for the Kullaberg Vingård, Höganäs, Skåne. Climate data was collected from the SMHI (Swedish Meteorological and Hydrological Institute) chain of climate stations and Kullaberg Vingårds own climate station. Soil data was taken from analyses done by Dr Georg Deutsch of the Viennese "Institut für Nachhaltige Pflanzenproduktion" for the Vingård and from SGU (Geological Survey of Sweden) Maps. Terrain data was taken from Lantmäteriet maps accessed via the SLU (Swedish Land University) portal. The data was analysed using Microsoft Excel and ARCGIS, with the model created running in Microsoft Excel.

4 Test Run Results

4.1 Kullabergs Terroir Description

Running the framework for Kullabergs Vingård, came up with the following terroir score and description.

4.1.1 Kullabergs Climate

The climate of Kullaberg has been derived from two main sources, the weather station established by the owners, at the site of the vineyard (since 2017) and the SMHI weather station network (based on the now defunct Nyhamnsläge point, with the station accessed from the SMHI website open data function). The specific results for the different sub-parameters will be broken down in the following section, with long term average data used instead of point data. Data from Nyhamnsläge has to be adjusted slightly for use at Kullaberg, due to the climatic differences. These come about due to the differences in height and distance from the sea (Nyhamnsläge is at sea level and on the shore, whereas Kullaberg is a kilometer from the sea and approximately 40 metres above sea level) with the distance between the two being approximately 1.5km.

- Spring Frost: The length of the growing season between 1998 and 2018 is on average 230 days, higher than the recommended minimum of 180 days. The average date of the final spring frost date over 20 years has been on the 88th day (29th or 28th of March, leap year dependent). This is comfortably before the budding dates in the end of April, for the grape varieties grown at Kullaberg. Kullaberg had a growing season of 236 days, instead of 240 days in Nyhamnsläge in 2018, the only full year data is available. Therefore, the long term average for Kullaberg was calculated, by removing 4 days from the Nyhamnsläge average of 234 days. This gives a score of 3.

- Heat Degree Days: A look into the most local temperature data shows that Nyhamnsläge is a full 1.24 Celsius warmer than Kullaberg on average (when comparing the data available). Due to the availability of Kullaberg specific data for 2018, the Huglin Index was calculated as 1083 for that year, which gives a weighting of 1 (the 20 year average calculated for Nyhamnsläge is 1186 which still gives a score of 1).

- Flowering Season Rain: Precipitation overall, shows an average of 706 mm per year in the 20 years collected at Nyhamnsläge, with a minimum of 454mm and a maximum of 879mm in 2007. The available data from Kullaberg, showed an average monthly difference of 0.4mm with Nyhamnsläge (with Kullaberg being drier). The daily averages for June and July, are 131 percent of the daily averages throughout the rest of the year, therefore a weighting of 1 is achieved.

- Ripening Season Rain data shows that the daily average of August, September and October is 129 percent of the yearly daily average, this therefore gives a weighting of 1.

- Branas Index: When calculated using the 2018 data, the Branas Index gives a result of 2917, as opposed to 4710 when calculated using the long term data. These long term figures were calculated by adjusting the temperature and precipitation data for Kullaberg, by using the differences from the long term Nyhamnsläge average. The figure to be relied upon here, is the long term average which gives a model score of 2. While the 2018 score would also be 2, this cannot be relied upon as a reliable source of data, due to the lack of rain during 2018, which was 212mm less than the long term average.

4.1.2 Kullabergs Terrain

- Aspect - At Kullaberg, the vines are grown in a South, North pattern and have no landscape features blocking the vines to the south. This takes full advantage of the solar radiation available, giving a score of 3.

- Slope of the fields are below any problematic level, however using GIS Raster data from the SLU Geodata extraction tool, it is clear that the average slope of the two fields is a low 2.6 percent, this gives a score of 2.

4.1.3 Kullabergs Geology

As mentioned previously, the geological data is based on soil analyses done for the vineyard by Dr Georg Deutsch of the Viennese "Institut für Nachhaltige Pflanzenproduktion". The analyses were taken from both fields that are in production at the vineyard, with scores being taken for the average of the two fields. The soil analyses were taken at different times, with one field being taken in 2016 and the other in 2018.

- Soil pH here is considered "moderately acidic" by the soil analysis experts. The actual pH levels are 5.9 in one of the fields and 5.8 in the other, this on average gives a score of 2.
- Drainage within the soil of Kullaberg was researched to follow the procedure defined. Since humus content (1.6 and 2.1 percent respectively) is above 10 percent of clay content (15 and 13.8 percent respectively) but Calcium Carbonate levels are below 0.5 percent, this gives a score of 2.
- Texture here gives a score of 1, due to humus content being on average below 2%.
- Sodicity at Kullaberg when measured using ESP, gives values of 0.7 and 0.8 for the fields respectively. As this is below the 10% threshold, the score is a 3.
- The depth of the soil horizon until the start of the drainage pebbles, is 70cm, with systems below made up of pipes and stones, this gives a score of 3.

Table 2: Table of the actual results from Kullabergs Vingård and the corresponding scores for the model. When two values (for the two fields) exist, the average was used for the code value.

Kullabergs Vingård			
Category	**Sub-Parameter**	**Data**	**Codes**
Soil	**Ph**	5.8, 5.9	2
	Drainage	2	2
	Texture	1.6, 2.1	1
	Sodicity	0.7, 0.8	3
	Depth	0.7	3
Terrain	**Slope**	2.6	2
	Aspect	S	3
Climate	**Spring Frost**	230	3
	HDD	1083	1
	Flowering Rain	131	1
	Ripening Rain	129	1
	Branas Index	4710	2

As seen in table 2, the scores for Kullaberg are varied, with climatic scores being worse overall than other sub-parameters (unsurprising considering the Scandinavian context). After being put through the framework, the terroir ratings were calculated. Kullaberg can therefore be described as having a terroir rating of 0.76 in the original classic method, 0.51 in the original inverted method and 0.64 in the original equal weights method. Using non-original weighting systems would give a score of 0.67 if all the sub-parameters and categories were equal and scores of 0.7, 0.6 and 0.65 (for classic, inverted and equal weights) if all sub parameters were equal but the categories were different (a graph of the different scores is shown in figure 5). The average of all the different weighting systems would provide a terroir rating of 0.65 for Kullabergs Vingård.

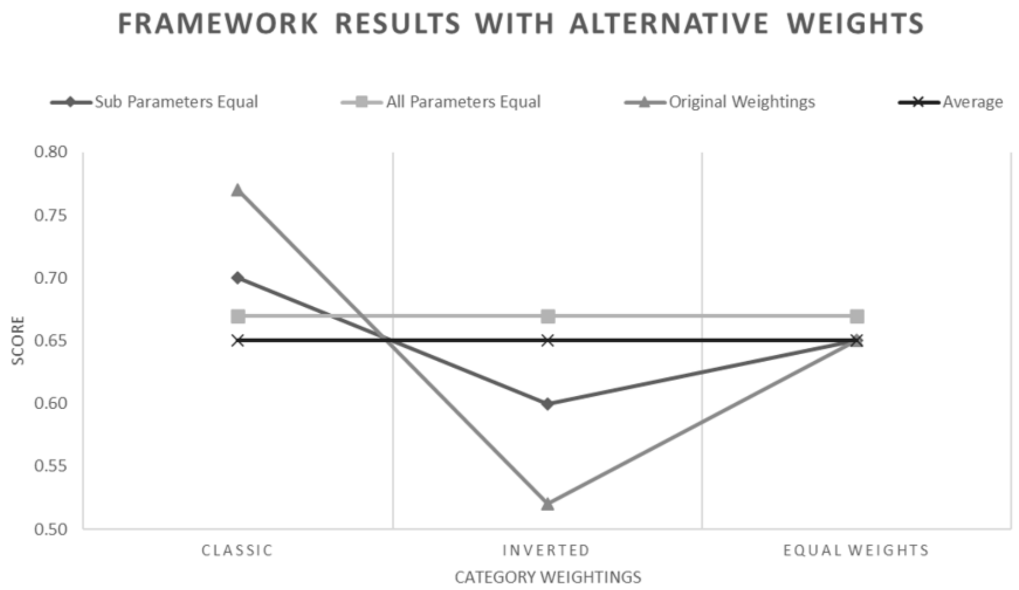

Figure 5: The different framework scores for Kullabergs Vingård

4.2 Spatial Expansion

As the framework is expected to be able to assess and accurately describe differences within terroir for larger areas, the next step is to compare how unique the terroir of Kullaberg Vingård is in comparison to locations in the rest of Skåne (the same geographical region). If similar scores were seen throughout Skåne, the terroir framework would be seen as not sensitive enough, whereas, if the results would be wildly different, there would be an understanding that something maybe askew within the priorities. A well functioning framework would show some score differences within regions but not too extreme.

To test the differences within the region, thought was put into what sub-parameters to look at. Terrain and geology qualities change on very small scales and sometimes due to anthropogenic factors (i.e. one field may have low soil scores due to a previous crop affecting the pH with the neighbouring field containing a different historical crop that contributes to the texture). An additional example would be terrain, whereby one field has a perfect slope for vines, whereas the neighbouring field is too flat for heat exchange. Since these changes do not occur regionally and linearly, it was decided to test the framework with different climate results for different locations within

Skåne, while using the same terrain and geology scores as Kullaberg. To do so, work was done to establish how many locations within Skåne have sufficient SMHI data to cover the 20 years needed for long term data and the parameters that are necessary for the framework. Only 10 locations were found that fit these requirements, therefore, although care was taken to have a even distribution of similarly distant climate stations that would cover the entire region, the availability of the stations made it so a truly accurate ”net” over the region was not able to be achieved. An abortive attempt was made at interpolating the data between the 10 points, but since data over the long term was only available for these points and no areas in between, it would be impossible to justify accurate interpolation between these points and therefore the climatic parameters were limited to the points and not in between.

The sub-parameters were collected and the framework was run to assess the climatic terroir scores of these 10 different data points in Skåne. The following map (Map 1) shows the framework scores (using the average terroir ratings). Kullaberg shows a slightly above average score, with the differences in the region slight but different enough to ascertain that the framework is sensitive to local changes.

When looking at the specific numbers behind these sub-parameters, it can be seen that Kullaberg is ”worse” than average in 3 out of 5 climate parameters as seen in table 3. For a more in depth look at the differences behind the sub-parameters, see the maps 2-6 in the appendix.

To assess how homogeneous (similar throughout the region) the Skånsk climatic regime is according to this framework - the climatic sub-parameters were looked into more closely. The range for each sub-parameter was calculated and its total as a percentage of the mean - this data can be seen in Table 3. Since the ranges were varying percentages of the mean (the highest being the Branas Index range of 74% of the mean) it is difficult to state with certainty that Skåne has a homogeneous climate terroir. This is good for the assessment of the sensitivity of the framework though, with differences being clearly seen throughout the region, maritime climates getting a higher terroir rating and inland climates getting a lower one.

4.3 Temporal Expansion

A final step to assessing the usefulness of the framework, is to look at it in a temporal vein, i.e. in a climate change perspective. To do this, the components of Kullabergs terroir were looked at through the lens of three different predictive models for radiative forcing (henceforth referred to as RCP’s 8.5, 4.5 and 2.6). These predictive models are used by the SMHI (Swedish Metereological and Hydrological Institute) to predict weather conditions up to the end of the century based on data established by the IPCC (Intergovernmental Panel on Climate Change). These models take into account different possibilities of climate change up to the year 2100 and provide clear predictions for changes based on varying years for peaking greenhouse gas outputs, where RCP8.5 has a high prognosis for extreme climate changes, 4.5 an intermediate one and 2.6 a low one. The names for these models are based on the predicted radiative forcing (in watts per square metre) in the year 2100. The predictive data

Map 1: Map of average terroir scores throughout Skåne

was taken from the SMHI for Skåne Län, and assessed by looking at the difference of increase in average/maximum temperature and precipitation for the last decade of the century (2089-2099), compared to the average increase predicted for the last 21 years (1998-2018). This was added to the actual measured data gleaned for Kullaberg, to provide a predicted increase or decrease in the variables for the years 2019-2099. The climate variables and their scores in the event of these models coming true are presented in the following list.

- *Branas Index* - using the SMHI predictions for the years up to 2100 to calculate the Branas Hydrothermic Index, it was established that the totals would reach the following levels in the event of the three different predictions (the present day Kullaberg value is 4710):

  RCP8.5: 5963.41 (giving a score of 1)
  RCP4.5: 5283.26 (giving a score of 1)
  RCP2.6: 5083.47 (giving a score of 2)

Table 3: The different climate sub-parameters and their ranges within Skåne, additionally showing the range as a percentage of the mean and Kullaberg Vingård values

	Kullaberg	Mean	Range	Percent of the Mean
Spring Frost	230	221	69	31
HDD	1083	1175	323	27
Flowering Rain	131	124	24	19
Ripening Rain	129	122	22	18
Branas Index	4710	4725	3508	74

- *Heat Degree Days* - The Huglin Index for Kullaberg increases incrementally through the different climate prediction models from the present day value of 1083:

  RCP8.5: 1743 (giving a score of 2)
  RCP4.5: 1359 (giving a score of 1)
  RCP2.6: 1182 (giving a score of 1)

- *Frost Days* - For this, we look at the SMHI final frost date, where even with only the final spring frost day changing the results look like the following:

  RCP8.5: a final spring frost day of Day No. 53 (giving a score of 3)
  RCP4.5: a final spring frost day of Day No. 75 (giving a score of 3)
  RCP2.6: a final spring frost day of Day No. 82 (giving a score of 3)

  Since the final spring frost day has been on average day no. 88 for the past 21 years, these predictions would provide no change in the framework score. If anything, they would cement the status of Kullaberg Vingård as a non frost issue location.

- *Flowering and Ripening Season Rain* - Data shows that flowering season rain would not change very much, with the maximum change being a 5 percent decrease of the daily average in the RCP2.6 prediction. However, ripening season rain would change slightly more (an increase of 10 percent in the event of the RCP8.5 prediction and 5 percent in the event of the RCP4.5 prediction). Additionally, more haphazard precipitation conditions would occur during the growing season. Since the daily averages for the flowering and ripening season would remain higher than the average for the rest of the year, a score of 1 for all of the predictions remains (see figure 6 for a graphic illustration of precipitation changes through the different predictive models).

Within the near term context of climate change, it is only the sub-parameters of the climate category that will change. Neither the terrain sub-parameters nor the geological sub-parameters will be expected to change in any significant or predictable way due to climate change within the next 80 years. Therefore to assess the framework in this temporal expansion, only the climatic sub-parameters were changed.

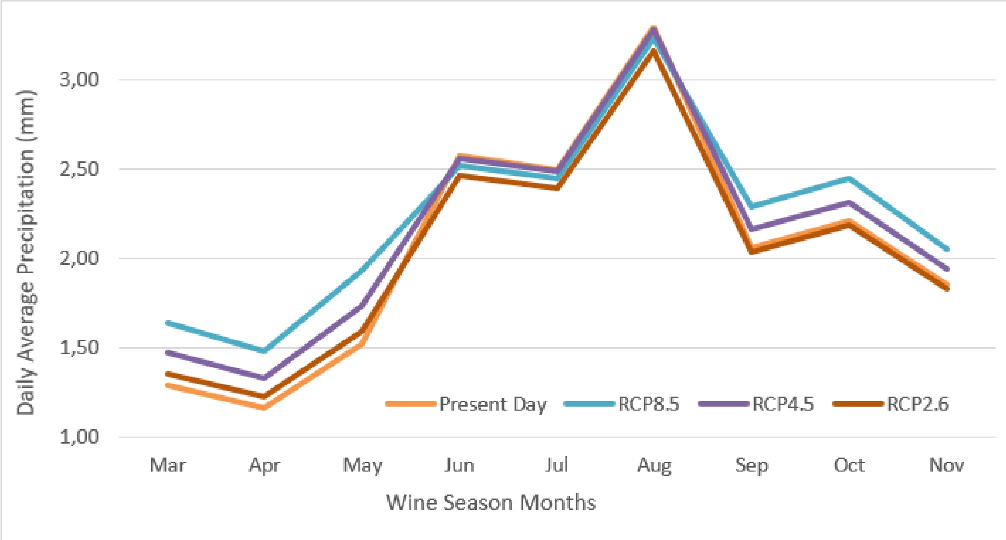

Figure 6: Precipitation changes in the event of Climate Change as compared to the present day

Table 4: Framework scores for Kullabergs Vingård in a climate change context

	Original Weightings			Non-Original Weightings				
	Classic	**Inverted**	**Equal Parts**	**Classic**	**Inverted**	**Equal Parts**	**All Parameters Equal**	**Averages**
Present Day	0.77	0.52	0.65	0.70	0.60	0.65	0.67	0.65
RCP8.5	0.79	0.62	0.71	0.70	0.60	0.65	0.67	0.68
RCP4.5	0.76	0.51	0.64	0.69	0.56	0.62	0.64	0.63
RCP2.6	0.77	0.52	0.65	0.70	0.60	0.65	0.67	0.65

After processing the framework 7 different times for each of the predictive models, the terroir ratings (including averages) were compiled and put together in (Table 4). As can be seen, for Kullaberg Vingård in the event of a low level model of climate change, no change would be recorded in the average terroir rating of 0.65. In the event of a mid level model of climate change, the average terroir rating would be reduced down to 0.63. However, in the event of a high level model of climate change, the average terroir rating would increase to 0.68. These results show, that the developed terroir framework, is sensitive enough to changes in climate, to provide different terroir rating outcomes for various climate change possibilities, showing its usefulness in a temporal expansion context.

This concludes the results section, where the developed terroir framework was tested in three different contexts. Firstly as an in depth location trial run using data from Kullabergs Vingård, secondly to assess its ability in picking up differences in a spatial expansion, by comparing the climatic terroir ratings of Kullabergs Vingård with that of 10 other locations within Skåne. Finally, to assess the ability of the framework to respond to climate change possibilities, by looking at three possible climate regimes predicted for Kullabergs Vingård in the year 2099. All of these trials showed that the framework developed is sensitive enough to changes in the data but not too sensitive as to radically alter outcomes for the same location.

5 Discussion

Before discussing the performance of the framework itself, it is prudent to loop back to what other research into similar vineyards has uncovered. Work on northern viticulture by (Karvonen 2016) into the use of different parameters for wine growth, shows like in this case, that wine growth in Scandinavia is not a "myth" but in fact a distinct possibility. Research done by SLU (Sverige Lantbruksuniversitet) students (Alsanius et al. 2014) show similar terroir ratings (albeit in a very descriptive rather than statistic manner) with different sub-parameters for the Bjäre peninsula north of Kullabergs Vingård. It has however been very difficult to find other studies that have attempted to use a scientific, repeatable framework for terroir of specific locations within or outside of Scandinavia - therefore, the results of this framework cannot to a large extent be compared with other work.

5.1 Sub-parameters and their contents

When laying out different vineyard characteristics, care was taken to use an all encompassing setup, however there are some sub-parameters that would have been possible to add in and maybe important to do so in the future. One of these, would be a sub-parameter that assesses the effect of the direction and strength of wind on vines. This is not particularly easy to do, as vines serve as their own windbreak and therefore the effect of wind is not a uniform one. However, a wind direction and strength vector could be something to develop, based upon topography and wind data values. This would have to work within the slope gradient sub-parameter limitations, as this already uses temperature exchange for a minimum value, connected strongly to wind dynamics. Another sub-parameter to add would be the propensity of extreme weather events, such as a freak hailstorm which may destroy vines at unexpected times (this maybe more important within a climate change perspective as these events are predicted to increase in number). While this again would be very difficult to assess in a scientific manner, data could be found to establish the likeliness of an extreme weather event in an average year and to release a score that would help to decide on a vineyard location. These two sub-parameter possibilities are just some very specific examples that could be added in to a future terroir framework. Other vaguer possibilities include an entire new category involving ecosystem health. When looking at terroir and the quality of a wine grown in a certain location, the health of the entire ecosystem maybe an important facet to take into account. This category, could include sub-parameters as varied as biodiversity indices within a certain soil horizon or a measure of ecosystem services provided by that location.

Additionally, when looking at the sub-parameters used within the framework, there are some that have been difficult to define and some of the definitions can be argued with. These include spring frost, where it maybe important, to look at the time difference between final spring frost dates and budding time (which changes on grape variety), rather than just the length of the frost free season. Another example would be the Branas and Huglin Indices, which use a season end of August and September respectively, to look at humidity and heat sums, this is untrue for Sweden where the harvesting continues until October. The argument could be made to increase the number of months used within the formula, even though that would stop the ability of comparison with other wine growing regions in the world. A non climatic example of this is the depth sub-parameter, while it is generally true that a larger soil horizon reduces water stress and therefore is worse for grape quality, the actual numbers vary very much and it may not be correct to use these specific depths. A terrain sub-parameter that maybe discussed is the slope gradient upper limit, there are some regions of wine growing that are very proud of growing grapes on very steep slopes, one of these is the Mosel region of Germany, where the worlds steepest vineyard gradient of 65 *degrees* is recorded (far higher than the 15 percent upper limit used for our framework). Additionally, the index for this sub-parameter can be said to be based on economic factors rather than the strictly physical factors that should be used. Both of these points lead to the possibility of this index needing to be reviewed in the future.

5.2 Statistics

One of the possible benefits of the developed framework is the fact that 7 different options for statistics of the framework have been tested and scores remain broadly similar, however if the framework was used continuously, two decisions need to be made. Firstly, what category weighting system should be used, which is basically the question of, what element of terroir is most important? Geology, terrain or climate? Secondly, once this is decided, the next question is, should every sub-parameter within each category be equal, or should there be a distinction based on ranked factors, as brought by Itami, or other subjective notions. If the choice of one the options needs to be made, the advice of the author of this paper would be to use the "sub-parameters equal" "equal parts" method of weighting, which allows all parties to be catered for when it comes to the argument of terroir importance, but removes any hierarchy within the categories.

It may however, become necessary for all the different weightings of the framework to be used, if it is to be relevant for different wine growing regions. An example of this could be in wetter wine growing regions, there one would want to lower the importance of the sub-parameters that look at precipitation, as they are "moot" to an extent in that region. For this reason, the different weighting options are considered an integral part of the framework described in this paper. Therefore, the continued use of the framework should only be made with the 7 different options, and the ability to compare the average terroir rating. An additional point that is important to mention with regard to statistics, is the fact that due to the scores of 1,2 or 3 for each sub-parameter, there is no option to get a score lower than 1/3. This artificially skews the average terroir ratings higher, and whilst not a problem within itself, it maybe prudent to add in a score of 0 as an option to allow terroir ratings ranging all the way between 0 and 1.

5.3 Quality of Geological Data

When looking at the geological data from Kullabergs Vingård used to test run the framework, some criticisms can be made. Firstly, the soil analyses used for the geological parameters were taken in 2016 and 2018 respectively, meaning that certain aspects of the geological parameters are out of date, and that the results are not as reliable as they could have been if they were taken at the same time. Aspects that could be out of date include the humus content, this will change through the use of cover crops between the vines, which is a method that is currently used by Kullabergs Vingård. The terroir rating is therefore something very dynamic, and cannot be relied upon to remain constant throughout time. Correct use of this framework for terroir rating would be contingent on the framework being rerun with new and updated data every wine growing season. This would be scientifically correct, and have the added bonus of dealing with one of the main issues with classic terroir systems such as the French AOC (i.e. that they are out of date and inflexible).

5.4 Climate Data and Change

The trial runs of the framework, were relying to a large extent on comparing data from Kullaberg Vingårds own climate station to the SMHI chain of stations. Whilst great care was taken to rationalise data by comparing averages and not point data, there is a possibility that comparing the climate data from Kullabergs own climate station where temperature measurements are taken every hour, to the SMHI chain where temperature measurements are taken at various lower time intervals (sometimes every 6 hours) is a mistake. In future use of this framework, it is essential to use the same source of data, or one that has the same rigorous standards of data collection and recording. This would probably be only possible if hourly measurements are taken in more locations (some of the indices such as maximum temperature require an hourly measurement).

Using the terroir framework, as an indicator for the suitability of a location for wine growing may sometimes be too limited. An example of this, is when looking at the effects of climate change on wine growth in Kullaberg. The framework shows that, climate change will cause precipitation to largely increase with temperatures (as can be expected). This would lead to a possibly better suited climate for wine growing in Skåne, however it will come with its own problems - these include increased humidity and a larger propensity for extreme weather events. Additionally, the benefits to the wine industry will only come about with the worst prediction for climate change, whereas the disadvantages of increased humidity will come at lower level predictions too. Looking at the terroir rating alone, would persuade someone to focus on setting up a vineyard, when in actual reality climate change is wreaking havoc with the surrounding ecosystems, as mentioned, other data needs to be taken into account when placing a vineyard. A final point to ponder is, there is sometimes an expectation that climate change will occur incrementally, smoothly passing through the different scenarios in a linear format. This however, will not be the case, with once in a 100 year climate events happening increasingly often, which should serve as a warning to those expecting better conditions for wine growing due to climate change, and using terroir frameworks such as this one to back their theories up (Jones and Schultz 2016).

5.5 Sustainability

This brings up an additional topic not mentioned previously. When developing a framework such as this one, there is a necessity to look at how its use could affect agricultural practice. In the modern agriculture context, where terraforming (large scale soil deposition or removal), and wholesale soil transplantation can be done before the sowing of a field - there is a danger that vineyards may become carbon copies of each other. With each vineyard using techniques to perfect their terroir rating, but destroying the natural ecosystem in the process. This is true not only with the geological category, but with the climatic category too - drip irrigation and greenhouses reduce the need to worry about natural precipitation, temperature and humidity worries but also can contribute to water shortages, sight pollution and other biodiversity worries. The important point is to ensure, that any scientific framework remains a diagnostic tool to work with nature, and not another implement to aid and abet the continued destruction of habitats.

5.6 Terroir vs Vineyard Quality

This paper has tried to marry the concepts of terroir and quantifiable vineyard quality. This has been done by assessing the terroir of a vineyard based on its physical characteristics. Can therefore a low score in this framework point to a so-called "bad terroir"? The author believes this to be the case as a conceptual pointer. This framework would be for use by vineyard owners to test their vineyard characteristics, and to describe their terroir based on these quantifiable indices. A low score in the framework does not have to mean that the produced wine is of low quality, but it does mean that the terroir is of low quality. This is quite exciting, as it allows wine quality to be removed from vineyard quality, and different frameworks be used to calculate both of these points. Taste tests can continue to be used for wine quality, and married with vineyard quality, so that both the terroir and its expression can be discussed in quantifiable ways.

6 Conclusion

In the introduction, there was an aim and a list of requirements for a terroir measurement. The aim of suggesting a defined quantitative framework, that can be used to measure and describe the terroir of a specific vineyard has been achieved. It was satisfied, by using a pre-existing framework for placement of vineyards. This was adapted to terroir, through the research and finding of relevant indices for each of the sub-parameters of the framework. 7 different forms of calculating the statistics were developed, based on different viewpoints from within terroir science. The list of requirements, had asked that any usage of terroir measurement needs to be repeatable, based on objective science and have backing in previous work. All of these can be said to be true with the developed framework.

The developed framework was test run using data from Kullabergs Vingård in Skåne, Sweden for a present day view. For a wider spatial test, the framework was run with different climatic data from points throughout the region, to assess the ability of the model to see localised differences in terroir (but not overamplify them), which it succeeded to do. Additionally, the framework was run in a temporal expansion, by adding predicted climatic data for 3 different future climate change scenarios. The framework proved its worth in this occasion too by showing different outcomes within the different predicted situations.

The developed framework has reduced the cloud of vague and varying definitions surrounding terroir, to a calculation based on 12 easily measured sub-parameters. This, in the view of the author, can be very useful for future development of the wine industry and its sustainability. For many years, the wine industry (especially in Europe) has maintained similar growing locations, leading to well known wine qualities and characteristics. In a future of climatic change, all tools will be necessary to allow continued wine production, both in newly suitable areas for this, and areas that have produced wine for a long time but need to adjust their process. One of these tools is the developed framework, and the hope is that this can be used as an easy but in depth solution, for countries such as Sweden that need a "quality" wine rating system, to be allowed to maximise the profits from this exciting field.

To conclude, whenever trying to look for the essence of terroir, or to remember the blend of factors that affect the wine we happily consume, it can be helpful to look to this saying from Southern Germany: "The vine is the mother of the wine, the soil its father and the climate its destiny".

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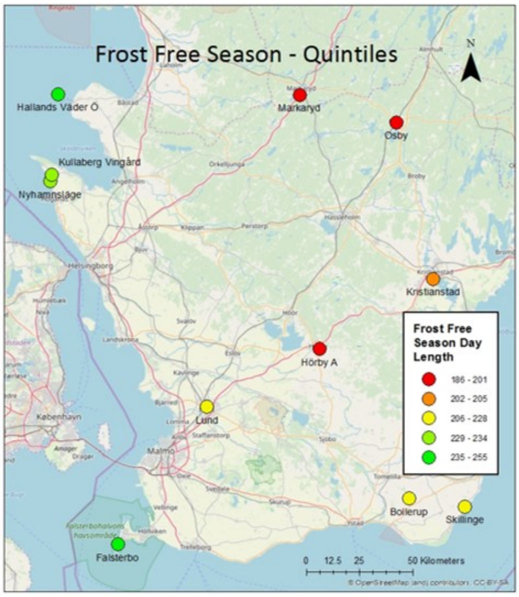
8 Appendix

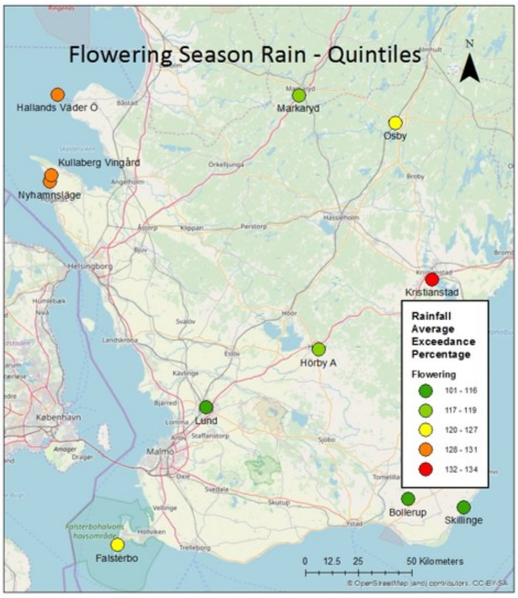
8.1 Climatic Parameters of Skåne

For a more in depth look into the specific numerical differences throughout Skåne for climatic terroir sub-parameters, the following series of maps illustrates the spread. It is difficult to follow a defined pattern throughout the sub-parameters, this is where additional climate stations would be useful. Map 1 is a repeat of the map shown in the results section, whereas Maps 2-6 show the specific breakdown of climate sub-parameters in Skåne.

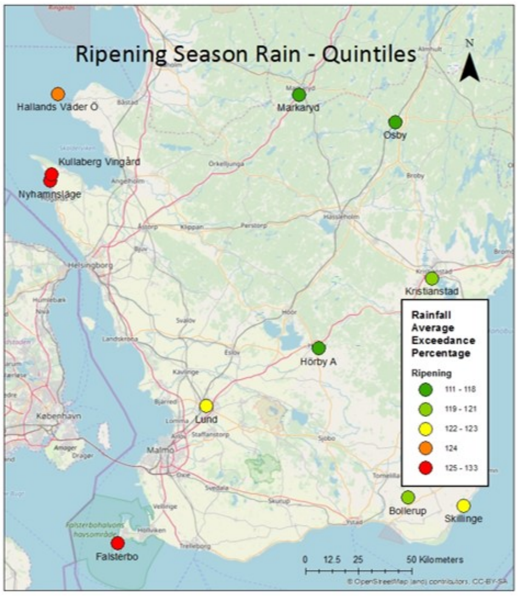
(a) Map 1: Map of average climatic terroir scores throughout Skåne



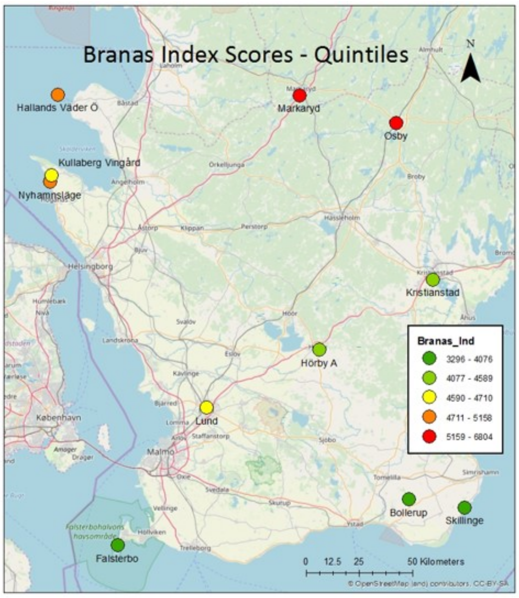
(b) Map 2: Frost Free season length in days throughout Skåne



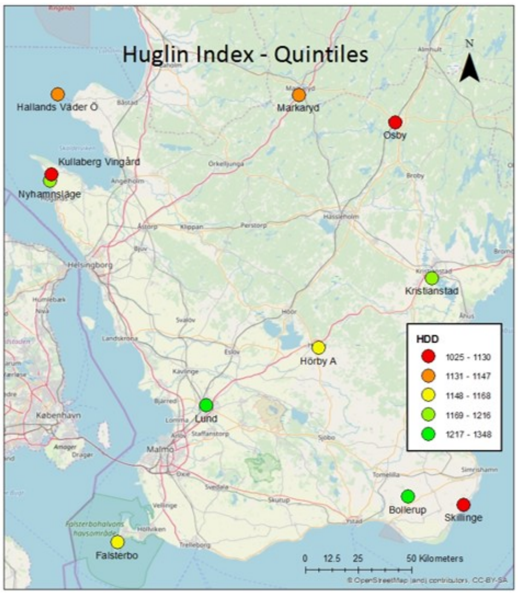
(a) Map 3: Flowering Season Rain throughout Skåne



(b) Map 4: Ripening season rain throughout Skåne



(a) Map 5: Branas Hydrothermic Index scores throughout Skåne



(b) Map 6: Huglin Index scores throughout Skåne