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Agroforestry Systems in Wine Production-Mitigating Climate Change in the Mosel Region

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Abstract: As Climate Change starts to show substantial impact on viticulture, winemakers are under pressure to implement sustainability transformation to maintain future production. This article deals with the effects of agroforestry system use on wine production and marketing in the German Mosel Region and reviews its challenges and benefits regarding sustainability transformation. The study is based upon qualitative interviews and field visits, researching farmers' experiences with an agroforestry vineyard in the cool climate wine growing region and reviewing the production methods on-site. Applying Sustainability Levers Theory, the article shows that the use of agroforestry in viticulture targets deep leverage points of the food production system, enabling sustainability transformation by providing positive effects on production and marketing. The article thus concludes that there's a potential of mitigating challenges of climate change, sustaining the wine production due to the implementation of agroforestry.

Keywords: agroforestry; cool climate viticulture; sustainability transformation; climate change; Mosel; wine

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1. Introduction

Viticulture has millennia of history from roots in the middle east [1] (p. 26) spreading to today's expansion across every continent of the globe. Around two thousand years before now, the Romans spread the cultivation of vine grapes (*Vitis vinifera*) and vineyard work across their European Empire throughout Central Europe until the border of Germania Magna on the Rhine. The first Europeans to step foot on the American Continent in the 10th century allegedly called it *Vinland* after finding wild fruits growing in the forests [2]. The climate of both the landing area of Leif Ericsson in today's Canada and the German Rhineland region is what today we consider a cool climate region for wine growing [3] (p. 4), with average temperatures that are significantly lower than those Mediterranean conditions around California, Chile, Southern Europe, or Shandong. With the Romans introducing the vine plant to Germanic soil, the Mosel region was first taken under large scale management to produce wine for supply across the roman empire [4] (p. 95). With the local cool climate conditions, they perhaps unknowingly implemented varieties that slowly adapted to the extended vegetation period, humidity and lower average temperatures of the Mosel for centuries to come. This resulted in wine grapes that have a longer ripening period and thus the ability to represent more aroma and terroir [3] adding to their popularity in cultivation. Today's science assumes that the vine plant as a wild variety originally ranked on trees following its cirrus behavior and that the people of ancient civilizations adapted this system, letting vine plants grow next to trees, using them as a climbing aid [5], forming an agroforestry system.

With the currently unprecedented changes of the 21st century to viticulture regarding climate change [6–8], agriculture in general and viticulture especially is turning their attention back towards the implementation of growing systems that integrate trees into

production to help mitigate the unfortunate outcomes of current developments. Looking back on the evolution of viticulture, the combination with agroforestry, adding trees with crops or livestock to the vineyard, has been largely done in a niche. Currently however, agroforestry in viticulture has reentered the field of attention, gaining significance in potentially making farming sustainable for future generations, mitigating outcomes of climate change.

This article deals with sustainability levers and viticulture in an agroforestry vineyard in the Mosel Region in Germany. Sustainability Levers are "places in complex systems where a small shift may lead to fundamental changes in the system as a whole" [9] (p. 30). Using the Sustainability Levers perspective helps identifying the impact of Agroforestry System use on wine production. Thus, the goal is to review current challenges the winemakers are facing and research the sustainability effects of agroforestry system use on wine production, as well as consequences linked to sales and distribution of the wine. The article gives insight into an agroforestry site that has been in use for over 15 years and links the experiences of multiple involved farmers to sustainability levers theory by David Abson and Donella Meadows, giving a better understanding of the potential transformational change within the food production system. The agroforestry vineyard is located near the town Ayl on the Saar River (49°37′43.839″ N, 6°33′10.761″ E) which is part of the Mosel Wine Region. The region is known for its cool climate grape production and high-class white wines, mainly from the Riesling variety. Increasing weather extremes, changing economic relations and concerns of company succession drive the local farmers towards dealing with fundamental challenges regarding economic, ecological and social sustainability to their ways of production. The article concludes that there's a potential of mitigating the challenges and sustaining the wine production within the rediscovery of agroforestry wine growing among farmers, who are still in the process of understanding its challenges and benefits.

Research on agroforestry use in cool climate viticulture and its potential to mitigate climate change has so far scarcely been done, thus this article provides new insights into ways of coping with current challenges towards making viticulture sustainable.

2. Materials and Methods

In total 19 qualitative interviews with winemakers were conducted in the Mosel region using a semi structured interview guideline as part of a bigger research project concerning sustainability in wine production. The topics covered in the interview guideline consisted of general information on the winery, development of agricultural land, organization of the production process, inputs, marketing and distribution of final products as well as questions on the advantages and challenges regarding the use of agroforestry systems. 7 of the interviews were conducted with farmers implementing agroforestry into their production process, 6 of which were managing the same site in a rotary system for over 15 years, taking turns with management and wine production for one year at a time. One farm had just started the implementation of agroforestry and thus could not provide relevant experience on the production process.

All interviews were conducted on owner-operated farms in early 2022, lasting between 45 min and 2 h. This provided a comfortable setting for the interviewees and allowed a visit through the farm's facilities after the interviews. Visiting wine cellars, storages and agroforestry vineyards enabled an in-depth look into the wineries and their production methods, as well as an on-site review of the given information. The interviews were conducted in German, granting anonymization, the recorded audio was transcribed and coded with MAXQDA coding software creating a coding system of 7 first-level (e.g., Production, Distribution), 51 s-level (e.g., Vineyard, Spatial Development) and 39 third-level codes (e.g., Export Countries, Grape Varieties) with a sum of 987 codes. All interview quotes have been translated by the author.

Theory

The theory referred to in this article draws from the field of sustainability transformation research investigating the process of value creation within sustainability transformation processes [10]. The sustainability transformation of the food production system, present in the interviewees' winemaking farms, demands for a theoretical frame that can link current challenges and development to categories of different transformational potential. Through the theory of sustainability levers, we will gain a better insight into the extent that agroforestry changes the fruit production system.

Sustainability Levers describe pivotal points of intervention within a food system, to impact transformational change. Donella Meadows originally identified 12 leverage points, divided in 4 system characteristics from shallow (parameters & feedbacks) to deep (design & intent), to describe points of impact on a given system [11]. Shallow leverage points do have less potential to create profound change throughout a system yet are easier to strive for. The deeper leverage points of design and intent of the system are targeted, the more fundamental transformational change can impact the entirety of a food production system. Such deep points of leverage can be found in our empirical findings, for instance where farmers' whole production system is dependent on their choice of plant protection.

The leverage points and system characteristics displayed in Figure 1 shall serve as a general orientation when linking findings from the interviews to aspects of sustainability transformation.

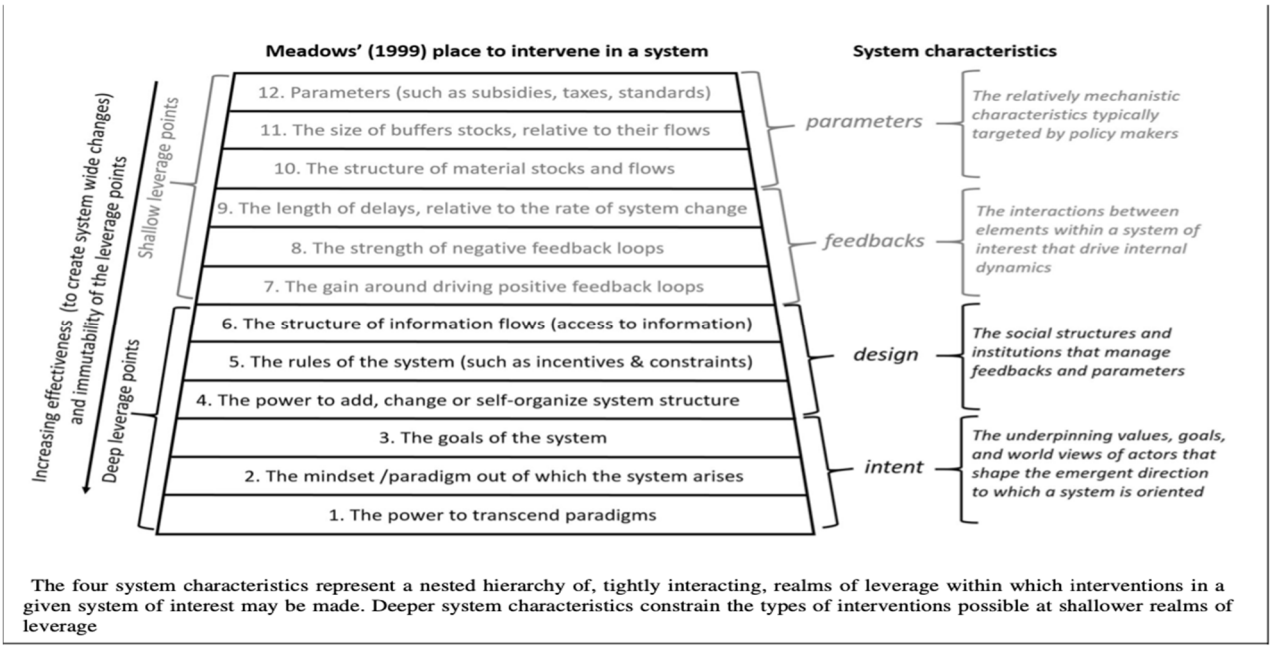

Figure 1. Displaying Leverage Points and System Characteristics [9] (p. 32).

Drawing on Donella Meadows` concept of sustainability levers, David Abson argues that most interventions for sustainability usually target tangible and easy to achieve goals. As mentioned in the parameters section of above's graphic, policy makers tend to prefer targeting these shallow points of leverage. Abson thus developed the notion of sustainability levers further and places the research around the three realms of "re-connecting people to nature, re-structuring institutions and re-thinking how knowledge is created and used" [9] (p. 30), representing a concept to identify deep points of leverage with high impact potential. Adding to Meadows theory, these three realms provide the ability to attribute deep transformational development to the farmers actions across the empirical findings. Applying the theory, we want to assume a more integrated perspective on the wine production with agroforestry that is taking place in the Mosel Region. Hence the following case study was conducted with qualitative Interviews, trying to understand the

production process from vineyard to vinification and marketing, including the motivational genealogy of tree implementation into the vineyard. Sustainability is a term of which the definition will remain dependent on the individual winery's situation since the farmers perspective is predominant for our analysis. However, the interviewees regularly referred to the social, economic and ecological aspects of their work, relating to the UN's Agenda 21 program resulting from the 1992 UNCED in Rio de Janeiro [12], this will be referred to as a base understanding of sustainability.

3. Results

3.1. Production Circumstances

The winemakers of the Mosel region are facing conditions veering from most circumstances in modern winemaking, because about 40% of the ~8655 ha vineyards in the region are set up in steep slopes with gradients between 16.7° and 68° which makes the region globally predominant in steep slope vine growing [13]. This form of cultivation has a long history with evidence of the Celts and Romans already using the inclined plantation on the riverbanks of the region's rivers Mosel, Saar and Ruwer to produce wine [14]. The angled vineyards provide the positive effect of increased sun exposure while reducing the base area, allowing for a higher yield per hectare compared to flat vineyards, facilitating viticulture in a region where climatic circumstances differ from those in classic wine growing regions like the Mediterranean. The skeletal rich soil in the Mosel Region further adds to the microclimate in that it keeps the sun's heat at level, while making the vine struggle for nutrients and build deep roots, adding to the grape quality. Since the Mosel is a comparatively northern wine region, it lies within the zone of cool climate viticulture [8], comparable to New Zealand's Marlborough region or Champagne in France. Cool climate zones traditionally feature an extended vegetation period with long and slow ripening of the grape over the course of the year. Resulting in minerally, fresh and fruity wines, the cool climate is commonly perceived as adding to the complexity of taste and finesse, creating a valuable food production system for the region.

However, climate change, high gradient and low adhesion make maintenance of the region's vineyards challenging, leading the winemakers to rely on contractors and foreign workers, predominantly from Romania and Poland, to maintain most of their parcels by hand. While manual vineyard maintenance has been largely substituted with chemical and mechanical treatment in many wine regions, the Mosel region must rely on manual labour because of its landscape traits.

The annual handwork cycle consists of pruning the vines in winter, binding the rods, pesticide application, defoliating and pinching out shoots in spring and summer, harvesting in late summer to autumn. This is resulting in working inputs between 1000 and 3000 working hours per hectare and year, depending on the steepness, accessibility and production regime present in the respective winery. Compared to flat profile wine regions in Germany whose management is highly mechanised, the working input in the Mosel region is up to 4 times higher, referring to an interviewee who manages both land in and outside the Mosel region (see also [15]). Thus, the labour costs for vineyard management in the region make up more than half of the total operating costs and are regarded as a challenge to economic sustainability. Besides the manual labour in the vineyard by foreign workers, the winemakers owning the winery themselves participate in tractor work like harrowing, weeding and applying pesticides and rely heavily on family members to partake in their everyday work. While the majority of working hours are spent in the vineyard making up around two thirds of the aggregated working time in the winery, the winemakers focus lies on the vinification, marketing and distribution of the final product.

3.2. Current Challenges of Production

Besides challenges surrounding the field of labour and weather extremes, changes in economic relations and company succession were voiced as the main challenges regarding the sustainability of overall production within the group of interviewees. While the question for succession mainly was debated within the respective families of the winemakers and dependent on individual interests, development of climate change and economic relations were seen as related to each other and potentially threatening the interest of future generations to continue business. The following part thus deals with the economic and ecologic challenges towards production following the value chain as stated in the interviews and their linkages to sustainability levers theory.

Because of the difficulties in acquiring foreign workforce, one interviewee got really excited when being asked about the specificity of manual labour in the vineyard, responding:

> "You are welcome to come, do that one day, then you don't come anymore. It's simple, who wants to do that? [Wine harvesting], it's hard work. Who wants to dig asparagus? These are questions… Only workers with a high wage gap do that. Like it was in Poland 20 years ago. As it was in Romania 10 years ago. But that is being compensated for more and more through EU membership. For a 12€ minimum wage that they want to raise from 9.80 or 9.50."—Farmer J.

Increasing wages for manual labour are thus representing a growing problem to winemakers. Not only does the demanding management of vineyards by hand require a monetary incentive for foreign workers. With changing production regimes and necessary adaptation of manual labour to the changing conditions in the vineyard, farmers are reporting that sensitizing staff for environmental change and teaching new techniques of sustainable vineyard treatment takes up an increased time amount. Labour costs growing to up to two thirds of the overall production costs does add a major concern for sustaining profitability and future production among the interviewed farmers. By experience of the interviewees, the increasing of prices accompanies a concern among them and their colleagues that the production costs could exceed the scale of economic sustainability, affecting the oftentimes adolescent successors in the family businesses to remain hesitant towards future takeover. This is both because customers might not accept an increase in price, opting for cheaper products by competitors and a subsequent development to insufficient funding for future production cycles. Thus, the farmers are holding back on passing the current price increases, induced by supply chain interruptions, crisis and inflation on to the customers. According to the farmers, targeting the issues of subsidies, work force and expenses on material flows from a top-down perspective could relieve the pressure on their economic sustainability. Meaning there is an increased wish for governmental intervention in the sector of rising production costs among the Mosel winemakers. Applying our theory here to understand the respective point of intervention this would target in the food system, governmental intervention via subsidies represents a shallow point of leverage represented in the Parameters [11]. Though a subsidy of foreign work could reduce pricing pressure in the short- to midterm, it cannot be regarded as viable over time. In the longer run, being reliant on external workforce is an integral part of the predominant way of wine production in the Mosel Region, expenses for foreign manual work force thus seem inevitable unless the production pattern can be changed on a deeper level, targeting the design and intent of the system.

Labour costs however are not the only challenging development the farmers have to deal with. Climate Change plays an ambiguous but challenging role in the wine producers' perception as well. The increase in annual average temperature associated with climate change has partially played out in the favor of most interviewed winemakers, resulting in the improvement of wines for the last 30+ years [7]. Hotter summers and extended vegetation periods have reportedly resulted in higher sugar contents in the grapes, enabling higher alcohol contents and different styles of vinification. When being asked

about effects of climate change on the wine production, one winemaker reflects on the past development:

> "We have benefited so far. When I was young, there was one super vintage in a decade, so in ten years there was one super vintage and two or three very good ones and then mediocrity and then one or two really bad ones, as the grapes were not ripe. And since the end of the 80s, the last really bad year was '84 and then it got better every year, so the grapes became riper, the Öchsle, the sugar values increased, the budding tended to be earlier. I know the figures from Bernkastel, there is a test station there, they have compared the vegetation data of the vines in the last 50 years and now find that in the last 50 years the Mosel has moved 400 km south, climatically."—Farmer P.

When we translate this statement into percentages, we see that the decades between World War 2 and the 1980s consisted of around 30%–40% good to very good wine harvests, while the rest 60%–70% was either of mediocre quality or was not ripe at all. Compared with a response to the same topic, another winemaker stated:

> "1984 was the last real bad vintage I witnessed. Since the 90s, there have been no more miserably bad vintages."—Farmer I.

This being said, the vine ripening earlier and more consistently presented a long-term addition to the overall produce value of each vineyard in the last 30+ years. For the mentioned period, all winemakers reported that in contrast to their predecessors' experience, climate change happened to increase the wine quality significantly from the late 1980s and early 1990s until the present time. The tipping point of this development however seems close, when considering other farmers' statements regarding the additional effects of climate change. For instance, when asked about weather events like heavy rain and flooding a farmer responded:

> "Big issue. Three years ago, we had a heavy rainfall event here and the mulch cover was ruined, too. When it comes out of the forest half a meter wide, the mulch cover can no longer compensate for it."—Farmer B.

Mulch covers consisting of shredded green waste are frequently used to mitigate the already existing issues of drought and erosion within the Mosel region, building a protective layer to the soil, lessening evaporation. Adding to extreme rainfall and flooding, sunburn on grapes due to increased periods of solar radiation raises concerns among the farmers:

> "[…] that is becoming more and more critical where sunburn occurs like in 2018 and 2019. You have to be very careful and we are already training our staff very well. The entire fruit-growing scene is actually familiar with the problem of sunburn. It occurred for the first time on a significant scale in '99. Before that, it was virtually unknown; it probably also occurred in '59 and perhaps in '76, but that was only on a small scale. At the time, these were the so-called century vintages."—Farmer G.

One more challenging effect of climate change indicating an end to the period of beneficial temperature to wine growth is displayed in deficiencies during the ripening process of the grape prior to harvesting:

> "Some of the grapes already start to ferment before they are processed. Say a later harvest always brings more aroma. And if you have to harvest Riesling early in September because otherwise, they would start to rot, then that's not the optimum. And you have to react much more in the cellar because there are also higher pH values, which means that the musts are more susceptible to certain microorganisms that you don't want. That has a lot to do with the high Öchsle degrees. And partly because of the dry summers, the nutrient supply for the grape's own yeasts is no longer so good. Then the musts also ferment less well."—Farmer Q.

The increase in annual average temperature has thus led to the vine plant entering a stress zone in years where drought and heat are especially present. While for over 30 years, sugar contents increased, adding to the wine quality while the vegetation period of the vine was still sufficient to build enough acids and other ingredients relevant to taste. Now deficient ripening and premature fermentation start to indicate major problems to the way of wine production linked to climate change. With the quote above mentioning a climatic shift 400 km to the south, not only the grape varieties and technical aspects of production are being challenged, but the whole production concept seems to be at stake. Yield losses through sunburn and an increased UV radiation result in the white wines producing phenols, which result in defective taste. Increased periods of heat lead to a shortening of the normally extended ripening period exclusive to cool climate wine growing regions. While extreme weather events such as flooding and hail threaten the plantations physical continuity. Being on the northern border of climate regions in wine production, the Mosel Region has been well adapted for the last 120 years but is facing major issues present in its production systems. Relying on Meadows' and Absons remarks on system characteristics, the challenges mentioned by the farmers can be linked to deep leverage points within the production, since the current development seem to target the overall design and intent of wine making. In the following section we focus on the group of winemakers using agroforestry, discussing their experiences around sustainability in production. After that we focus on agroforestry wine making and how it potentially can target the aforementioned challenges in the lights of sustainability levers.

3.3. Agroforestry & the Vineyard

Agroforestry means the combination of livestock, crops and trees on the same agricultural area (e.g., see the combination of vines and trees in Figure 2). Forms of Agroforestry can be regarded as an outcome of the neolithic revolution, when grazing pastures and field cultivation with livestock became a necessity for sedentary humans and date back more than 6000 years [16].

Figure 2. Author's photography of the agroforestry vineyard.

The production system's roots in wine production can be traced down to the early bronze age, where there's evidence for European Wild Grapes (*Vitis sylvestris*) being intercropped with willow (*Salix*), who's trunks acted as a climbing aid for the grape plant [6]. Nowadays agroforestry in viticulture is being made use of in traditional farming [17] and as a research subject to the potential of mitigating climate change effects, carbon sequestration and other challenging aspects of viticulture [18].

Current research has shown that the intercropping of deep rooting trees with vines produces an increase of water availability in the soil, resulting in an aquatic lift, making water accessible to the vine plants from depths they couldn't reach on their own [19]. The root system in addition provides an increased richness of the soil while preventing erosion through mechanised management or floods. The shading effect of the trees canopy minders sun radiation and provides cooling, resulting in normalisation of the grapes vegetation phase alongside preventing sunburn.

The agroforestry site referred to in this article was initiated by the University of Freiburg in collaboration with local authorities and winemakers in 2005 to research the interaction between trees (*Populus & Quercus*) and vine plants (Riesling & Sauvignon Blanc) on an area of 0.8 ha.

The parcel lies within the municipality of Ayl on the Saar River in Rhineland-Palatinate and is managed by the 5 winemakers within the same town. Resulting in each winery managing and harvesting the wine of one year, then handing the parcel over to the next winery.

All of the winemakers are working with conventional production systems without EU/Organic certification and have experienced the agroforestry system from the beginning. One winery works with the label of the "Association of German Prädikat Wine Estates", which recommends ecologic production for their members. All of the agroforestry winemakers however pursue conventional vineyard management, leaning on what is referred to as "integrated wine growing" [20]. This production method is not standardised but goes in the wine growing jargon as a management type that integrates ecologic thinking in the process of conventional wine growing. This results in an input of conventional pesticides into the parcel if deemed necessary by the farmer. The fertilization of the vineyards, including the agroforestry site, does exclude mineral fertilizer, opting for organic materials like pomace, green waste, or woodcuts, which are collected from local compost stations, fed by local residents. Confronted with the challenged production patterns in the face of climate change and weather extremes, the interviewees voiced a need for sustainability transformation and brought up the discussion of production patterns and the legitimacy of sustainable work within certified and non-certified wineries. All of them considered their ways of production superior compared to EU certified/organic production, explaining that especially the pesticidal varieties are less delimited while the additional bureaucratic effort to manage organic certified production is omitted. They were seeing it as an asset being able to transcend production regime boundaries if necessary, integrating agroforestry into their fruit production patterns. When asked for his perspective on certification and production methods one winemaker responded:

> "[EU certified/Organic Production] often excludes sustainability. The simplest example is herbicide, the glyphosate discussion. Several people will have told you that producing and applying glyphosate requires much less energy, resources, etc. than carrying out the same work mechanically. Mechanical application has a much worse ecological balance than chemical application. Now the question is simply how do you judge this chemical story, as the WHO has done, as probably carcinogenic, others say it is not carcinogenic at all. That is the only question, but in terms of sustainability there is nothing that is superior to the herbicide in terms of sustainability. So resource efficiency. If you define sustainability in terms of resource efficiency and fossil footprint, then that's the way it is. Nevertheless, we have said that there is no way around it, but we no longer use herbicides, we no longer use insecticides and we have not used agricultural

pesticides for 20 years. So we use the means of organic viticulture. Except for downy mildew."—Farmer C.

Taking the necessity of manual labour from foreign workers for granted, he voices a dilemma between mechanical vineyard maintenance, that requires more work intensity and chemical treatment that might induce carcinogenic compounds. Where organic production would limit the pesticide range to the use of copper preparations, the Farmer sees an advantage in lessening the mechanical work in the vineyard due to the exceptional use of conventional pesticides in the case of downy mildew. Rather opting for the conventional way of managing pests chemically has its representation in deeper leverage points, such as parameters and the goal of the system in sustainability levers theory. Understanding that means it is a decision of systemic quality to opt for conventional instead of certified production, the pesticide policies regarding the latter emerge as a key decision factor for the agroforestry winemakers to remain conventional. Sustainability as a concept to establish and promote within their production system is a clear goal among the farmers, however a homogeneous definition of the term was not provided. The implication of the quote above though is that a sustainable way of vineyard maintenance does exceed the frame of official certification. The farmers claim that due to their work with the agroforestry system, their perspective towards sustainable vineyard management such as practices of certified organic/ecologic and beyond production opened up. This results in the introduction of pomace and green waste used as fertilizer, a pruning style that demands less work and does less damage to the plants as well as a clear goal to reduce pesticides wherever possible. Regarding the issue of pesticidal limitations in certified organic viticulture though, all of the interviewees agreed on copper as the only possibility to mitigate mildew infection in organic production as being unattractive.

This ambiguity arises because mildew endangers the vine plant mainly around the blossom in late spring. During this time rain fosters the development of the pest, while the copper compound, solely permitted in ecologic winemaking, is easily being washed off the plants by the rain. Because of the lack of adhesion working with copper as a sole pesticide against mildew the cadence of application is increased, while time spent on tractor work, labour costs and working input are rising as well. Applying our theory here, again the systemic choice to not certify their production can be linked to two aspects in the food production system.

First, there are input aspects which were commonly mentioned early on in the interviews regarding monetary and work time efforts that are increased with certified production. Adding to the excess work and labour costs, the increased costs an implementation of ecologically certified wine making would carry along is regarded as unattractive either.

Second, the surplus gained by a certified product output which could justify higher product pricing is not fully believed, since the farmers rely on narratives of sustainability surrounding their sales practices already, linking their products prices to sustainable wine production and agroforestry specifically. While all farmers showed an extended understanding of their vineyards' natural substance and interplay between organisms, the main argument for remaining in conventional production, despite understanding agroforestry as part of sustainable agriculture, lies in the EU regulated restriction to copper products when dealing with mildew. This policy seems to shape the mindset out of which the production system of the agroforestry winemakers gains stability and constitutes a deep leverage point linked to the system's intent. The quote above also shows that besides the reduced chemical vineyard treatment with pesticides, the production process relies little on mechanisation and mainly on manual work. Apart from this being more cost intensive and requiring more material flows on a shallower level of the production system, the mechanised work serves a narrative of sustainability shaping an intent that connotes indulgent treatment of the vineyard, especially beneficial when justifying production patterns, marketing and selling the final product.

This means even though organic certification is rather unapproachable to the interviewees who are managing the agroforestry site, sustainability is a concept they adapt for

themselves as narratives of design and intent surrounding their production. Thus the experience-driven management of the vineyard, also regarding pesticide application, was frequently used to explain the individual farmers' way of production as superior to certified organic production. This narrative represents a way of showing the intent of the food system towards sustainability in the lights of the *re-connect* realm. As Abson notes about it, "a shift in the emergent intent in a given system of interest demands concurrent changes in its design" [9] (p. 35). If organically certified or not, through societal discussion about the remains of pesticides in the final product, the winemaker's awareness towards minimizing the pesticide input and their drive towards sustainability transformation is observable across all interviews. According to the farmer's experience, especially younger customers will frequently confront winemakers regarding their way of production, asking about pesticide use and production regime.

Contributing to the realm of *re-think*, the farmers show a distinct way of knowledge production in their process of sustainability transformation, that supports justifying and explaining the individual work flows as "real" sustainability in contrast to the supposed trade-offs that come with certified production. Despite the dilemma of pesticide use and resource consumption, negative press and societal perception potentially decrease the value of the winemaker's final products. All of which add to sustainability as a justification narrative and idea to increase resource efficiency.

On and off the agroforestry site resource efficiency is thus being closely linked to matters of sustainability by the winemakers, present in the majority of interviews. Through benefits regarding these factors, agroforestry as a means to exalt sustainability in wine production presents a major point of interest to the interviewees.

3.4. Challenges and Benefits of Agroforestry Wine Production

The wine production with agroforestry posits both challenges and benefits to the winemakers regarding their production regime and the potential of sustainability transformation. In parallel to the scientific findings mentioned above, drought resistance is a key benefit acknowledged among all interviewees involved in agroforestry. After 3 years of high heat and drought in the years 2018–2020 the winemakers were seeing advantages of the tree shades and water supply the agroforestry system provides. As stated by the interviewees, the sunburn was resulting in an approximate 30% loss of grapes due to sunburn on regular vine plantation in 2018, while only around 3% loss on the agroforestry site was perceived, increasing the yield in hot and dry years:

> "Yes, you can simply say that the yield is higher when nothing burns. If nothing burns due to sunburn, which is the most extreme form of solar radiation, then of course they also die. This was very clearly seen in 2018. Up to a third of the grapes in the control plants died and under these trees in the Arbustum project it was just 3%, which is very little. That was a beautiful effect."—Farmer C.

Reducing crop losses while protecting the vineyard from extreme solar radiation are features the interviewees link to both the ecologic and economic sphere of sustainability. The overall design of the agroforestry plantation provided systemic change to what the winemakers were used to, which resulted in major production benefits during changing climate circumstances as well as improvement of the final product. The shade provided by the tree branches and canopies mitigates the premature ageing process white wine sustains when being overexposed to intense sun radiation. A process that is looked after in red wine, being responsible for the typical taste, is regarded as a wine failure in commercial white wine, causing bitter tastes reminiscent of petrol:

> "Increased UV radiation has the consequence that more carotenoids and xanthophylls are formed. These are the yellow and red pigments that are in turn broken down in the next metabolization step into substances that cause the wine to fir or age more quickly. In addition, the formation of phenols also sets oxidation processes in motion more quickly."—Farmer C.

The shading of the agroforestry system thus reduces the UV radiation and adds to the product quality and longevity by mitigating premature oxidation and wine failure such as deficient taste. Besides that, farmers reported that the ability to provide windbreak and soil stability through bigger root systems decreased erosion, visible when visiting the vineyards.

Furthermore, the farmers stated that the agroforestry system helps cool down the microclimate within the vineyard, reintroducing longer grape ripening periods, common and distinctive to the region prior to the phase of climate change induced heat. Apart from that, the enrichment of the soil within the agroforestry system through foliage and general production of biomass and roots leads to higher water capability and resilience to extreme weather, as the winemakers observed. This, in addition to the roots capability to mitigate erosion, adds to the ability of flood resistance while increasing the amount of water available to the vine in periods of drought.

Referring to the challenging production circumstances mentioned above, pesticide use within the agroforestry vineyard could be decreased due to the grape architecture design that's being used. The perennial cordon pruning system, where the grapes are hanging higher above the ground make splash infection with mildew less likely. This pruning system is a novelty to the farmers in the region which allows them to reduce working inputs, subsequently benefitting to the economic sustainability when revisiting the annual labour input, which was deemed to be less than half of the average 1000+ h necessary on regular parcels. While the predominant vine training system relies on a short perennial stem of max. 1 m height, with several annual shoots of up to 2 m length, the perennial cordon establishes a solid horizontal wood stem on a height of ~1.4 m from which shorter shoots grow and create a hanging wall of leafs with the grapes on top. This training system allows for a less intensive management of the vine leafs over the course of the year, reducing labour and pesticide input, effectively reducing the operational costs compared to monoculture vineyards. The positive aspects of the cordon system are mentioned by a winemaker who currently managed the site:

> "The grapes hang upwards and the leaves hang downwards, which is actually quite nice, because then I don't need to lift the leaves, which is also a form of labour saving that we find very important. It is also sustainable, because at that moment we don't need to drive through it with the machine, but it falls down by itself. And then it hangs there, but this Peronospora is a soil-borne pathogen which, when it splashes up from the ground, always infects what hangs closest to the ground, the grapes have not been affected."—Farmer D.

Due to the increased height of the cordon system, the grapes are less prone to splash infection with mildew and downy mildew, resulting in a decrease of pesticide use. Besides the reduced danger of infection, the higher grape architecture allows for a more relaxed body position while working in the vineyard, which makes the work less tiring. According to the winemakers, this is well received by the seasonal workers, especially during hot summer periods.

Subsequently the winemakers are saving labour cost, fuel and emissions by decreasing both chemical and mechanised treatment with more efficient manual work. Concluding, the positive effects perceived by the winemakers on the wine production with agroforestry consist of drought resistance, lessened input for vineyard management, increased product quality and stability, labour cost savings, pesticide reduction and an increase of biomass. The implementation of agroforestry to the wine production can thus be seen as a systemic change targeting deep leverage points of design and intent in terms of an altering of the production patterns which helps to shift the farmers perspective from monoculture wine production to alternative methods. Shallower leverage points are targeted too, with changes in structure of material stocks and flows referring to the lessened work and material input, as well as a gain around positive feedback loops from customers appraising the product as visible in the section *Agroforestry Wine Marketing*.

3.5. Output

For the Agroforestry Site, an annual yield of 750–1250 L/ha is estimated by the interviewees, depending on the management intensity. This is about a fourth of the average yield expectancy that other winemakers, mainly from biodynamic and ecologic production regimes, within the case study reported (3000–5000 L/ha/y). Explanations for the smaller yield can regard the specificity of the rotary management system. When asked about this issue and how to potentially increase the output, one farmer responded:

> "One would have to think about the humus supply. Since it's someone else's job every year, everyone thinks it's the flood after me. I don't see it that way, but no one necessarily does more than they have to."—Farmer B.

The winemaker is indicating that due to the annual change of management, the agroforestry site's external supply with humus as a plant nutrient is low. As a result, the low annual yield is comparable to that of an extensively managed vineyard, other than of a vineyard that is regularly provided with humus. The increased input of fertilizing material however could potentially raise the output in harvest quantity.

Harvesting the grapes along with other fieldwork requires more knowledge than in conventional vineyards because the Riesling and Sauvignon Blanc varieties are planted randomized, not compromising the quality of the harvest, but adding to the workload upon harvest:

> "I was very happy with the grapes. It's a hell of a race though, we really jump from vine to vine and I look at them, say this is Sauvignon Blanc, this is Riesling and it is then harvested separately and the others, […] they do it that way too."—Farmer E.

This quote shows reference to the issue of deficient ripening process mentioned above. Despite climate change and extreme weather events, the grapes within the agroforestry site meet the winemakers' expectations. Apart from being satisfied with the parcels results in quality, the farmers tend to dial down the overall management inputs of the parcel. They reason it is because they don't get returns in yield the year after due to the rotary management system. Meaning the parcel tends to be less intensely fertilized and maintained than neighboring areas producing more yield. Despite lower efforts in maintenance, the agroforestry system is well received by the farmers and shows an increase in product quality:

> "I say in hot years I have natural shading, which is of course very good. This natural shading effect on the grapes has direct qualitative effects and consequences, so that one says the aroma remains somewhat brighter, does not go so much in the direction of early ageing notes, remains somewhat fruitier, somewhat brighter in the fruit. The entry of phenols and bitter substances in the skin is reduced."—Farmer C.

Upon harvest, the grape varieties are selected and picked by hand. After hauling to the winery, the grapes are being pressed on site with a mash rest of up to 6 h, then being fermented in steel tanks using either spontaneous or cultured yeast for fermentation, whereas the latter was more common. While the Sauvignon Blanc was processed into a dry wine, the Riesling was altered either dry or semi dry depending on the year's quality. After finishing fermentation, the wines are filtered, sulphured and filled into corked 0.5-L clear glass bottles, with the label sharing the same format and depiction of the antique servant indicating R for Riesling and S for Sauvignon Blanc. The depiction of the responsible winery on the side of the label changes with each year:

> "Exactly, it is vinified separately, which is then called Arbustum R and Arbustum S. For Riesling and Sauvignon Blanc. And the Arbustum R is a fine-tart Riesling and the Arbustum S is a dry Sauvignon Blanc. That's the concept behind it, these wines are labelled separately and with a label like this with a Roman servant on it carrying an amphora. And so, everyone markets their yields from

> this plant in the respective year with the same label. There's just a different name printed on it, who was the producer in that year."—Farmer B.

3.6. Agroforestry Wine Marketing

The Riesling and Sauvignon Blanc varieties stemming from the agroforestry site are marketed under the label name of "Arbustum" (engl. 'grove', or 'tree plantation'). With the label depicting an antique servant carrying an amphora on his back the label works as a reference to originality and authenticity, alluding to the wine being made like in the antiquities. As marketing instruments, the winemakers use online and direct marketing as their main channels, partaking in local events, national fairs and international trade meetings. Own websites as well as social media platforms are used to advertise the wines and touristic visits to the area. Farm 1 relies on exports for 60% of production, followed by national gastronomy and retail, farm 2 & 3 have a split in thirds among export, gastronomy and end consumers. Farm 4 uses a caravan site to market the majority of the products whilst the rest of wineries (Farm 5 & 6) sell to direct customers via self-collection and mail order alike. While all wineries have regular Riesling wines in their portfolio, the Sauvignon Blanc does introduce a new variety into 5 out of 6 product ranges.

The Winemakers say that the label's reference towards antiquity works as a strong marketing factor for the Arbustum products, adding to the narrative of agroforestry production, which leads customers to buy the annual produce quickly. The customer group consists of international tourists and the local tourist information as an intermediary.

"Wine doesn't speak"—(Farmer L), as one of the winemakers stated when asked for his marketing strategies. This statement exemplifies that the marketing of the wines implies direct sales practices including tastings and narratives being attached to the product surrounding the production and quality of the wines. Each winery had their own on-site tasting rooms for such purposes. In order to sell the agroforestry wine product within the individual winemaker's range, narratives of antiquity, craftsmanship, originality and sustainability were added into the sales process. This works in a way that customers, after buying wine stemming from the agroforestry system, occasionally make their way uphill out of town to enjoy their wine at the agroforestry site, adding an interactive experience to the wine sale. According to one winemaker, this experience increases the likelihood of customers returning. Finally, the winemakers are marketing the agroforestry wines successfully with an increased value of +10%–15% compared to the regular assortment. Hence the comparably low average annual yield of the agroforestry parcel facing a high demand, the production is sold out rather quick:

> "The demand is high. It's very limited, if you offer it, it's gone straight away. The people from the village or the tourist information take it immediately and with a big hand because the story is good and people can walk there, experience it and then open a bottle that comes from this vineyard, that's an experience for people."—Farmer C.

Experiencing the vineyard as a visitor can represent a deep leverage point within the realm of *re-connect* as mentioned in the theory by David Abson. Understanding that customers experience not only the wine but the place of origin in spatial proximity, represents a focal point for customers to deepen their knowledge of product origin. The positive aspects accompanying the vine growing and vineyard maintenance on the agroforestry site are being communicated by the winemakers so that there is mutual benefit in terms of general education about wine for the customer, but also in terms of potential long term customer relationship, which consolidates the winemakers' sales. Summarizing, the *re-connection* that happens through the agroforestry system entails an increase in social, ecologic and economic sustainability.

3.7. Future Implementation

Asked for their willingness towards extending the use of agroforestry into further parcels in the future, the interviewees responses remained ambiguous:

> "First of all, we have to say that it has no negative influence, which is good. It has no negative influence, neither in terms of quality nor quantity. And in the end, the water availability is higher when there is a tree next to it than when there is not. That surprised us, but of course we are grateful for such a result. Because, of course, if it were to get drier, there are various climate models of how things would develop here in northern, western Europe. If it were to get drier, that would be a thing."—Farmer C.

Despite acknowledging the benefits generated by the agroforestry system, the interviewees seemed unsure whether the climate change would really turn out to result in future years with intensified weather extremes. The quote above shows that the effects of climate change, turning the region into an overall dryer area are not yet completely believed. Predominantly speaking subjunctive, the winemakers remained hesitant towards approving future plans on planting an agroforestry parcel themselves. The non-use of byproducts from the present oak and poplar trees within the agroforestry site was mentioned as a challenge regarding the need for extra maintenance compared to regular monoculture vineyards. Poplar and Oak did not provide resources the winemakers are attracted to integrate in their production patterns. Alternatively, Fruit trees like plum, cherry or apple are of interest to them. Since the fruit trees offer the base for juice, spirits, or direct marketing of the fruits, they were imaginable to be integrated into the winery's everyday production cycles. The marketing and distribution of implemented fruit trees was deemed attractive for it allowed the combined production and direct sales of fruits, juice and cider.

> "That would make sense, I could imagine apple trees, for example. That would make sense to me. Otherwise, for me the experience is also about the cultivability, does it all work, can you get through with the tractor, […] This mechanizability just goes in the direction that we have seen, trees don't bother us."—Farmer B.

The overall impression given by the farmers involved in agroforestry wine growing seems to be impressed with the positive effects of the site as mentioned above. While the critique among all interviewees tends towards the preservation of accessibility and a more integrated agroforestry system. The latter meaning that the tree and vine combination is wished to be more adapted to the production capacities of the involved winemakers. Despite the farmers positive experiences, the idea of different tree varieties other than poplar and oak was thought of as a secondary option. Most farmers anyways did prefer agro-photovoltaic installations as a future innovation over the current agroforestry system. In this they found advantageous, that with agro-photovoltaics it would be possible to have electricity as a valuable byproduct of the production site. While on the other hand uncertainty prevailed regarding the ripening of the grapes underneath the imagined photovoltaic enclosure because the shading effect of the photovoltaic surface could be too strong. The preferability of agro-photovoltaics could indicate potential development towards a combined production pattern that involves multilevel usage of vineyards, co-producing fruits, timber and electricity while benefiting soil and climate. The ambiguity towards implementation seemed to be of twofold motivation:

First, the agroforestry site in presence is acknowledged with its advantages, yet criticized for not producing comparable output to monoculture vineyards. Via the theoretical understanding of agroforestry as an alternative production system with deep leverage impact to viticulture, this problem points both to shallow points of intervention which mean the material in and output of the plantation and the ideal or intentional level of the food production system. Overall, this process embodies what the *re-think* realm is aiming

at, by a problem oriented and mutual learning process of which the results are being voiced via critique by the winemakers

Second, the farmers' concerns about the lack of economic incentives regarding the work with agroforestry can be linked to the underlying mindset of profiteering, induced by the challenges mentioned in the introduction regarding climate change, changing business relations and succession. Contrasting deep and shallow points of intervention, could shed light on the issue that besides the financial threat put to the winemaker's situation by current developments, an opting for the implementation of agroforestry could diminish the base for their struggle substantially.

4. Conclusions

In the light of climate change, increased costs of production and environmental issues, agroforestry with viticulture seems like a cultivation form targeting deep leverage points within the food production system of wine. Agroforestry in Agriculture has reportedly increased land use efficiency for making the harvest of several crops on the same site possible, creating higher output per crop compared to separate plantations, thus fostering product diversity. In the case of the agroforestry site treated in this article, the land use efficiency could not be made full use of, since poplar and oak are not integrated as by-product producing entities in the production process of the local farmers. Also due to the specific management system, the production potential of the site was not exhausted. However, the challenges mentioned by the interviewees, consisting of labour costs, vineyard management, climate change effects and pesticidal choices were affected positively by the agroforestry system. The specific pruning regime on the parcel allowed for a management style that was more cost efficient and demanded fewer working hours with less input of pesticides than on regular parcels. However, the manual and mechanised maintenance in the vineyard required an adaptation from the involved work forces, resulting in teaching the pruning teams and carefulness when maintaining via tractor. Through the trees' roots and their function as windbreaks, the amount of erosion in the agroforestry vineyard was decreased. The drought resistance experienced by the farmers marks another deep leverage point in the agroforestry system that addresses the food production systems design and intent in the realm of *re-structure*. The use of agroforestry reportedly helped mitigate insufficient ripening that occurs as a result of climate change. Further rise in sustainability as indicated by the winemakers happened through increased water supply, shading and space for biodiversity the plants provide each other. In Addition to the major transformations to the standard ways of production, the variety of Sauvignon Blanc diversified the product range of the involved wineries. Sustainability and authenticity as a marketing narrative accompanied the agroforestry products that were being sold, adding to the popularity of the wines. This can be linked to the power of feedback loops described by Meadows and the *re-connect* perspective by Abson to reestablish a connection between production origin and consumer. The theory helped see that the unassertiveness towards the extended implementation of agroforestry in wine growing can be linked to matters of deep leverage points such as the intent and design of the agroforestry system.

To give an overview, the following Table 1 indicates the impact of agroforestry wine production found in this research, attributing it to the realms of deep leverage represented in sustainability levers theory:

Table 1. Relating Realms of Deep Leverage and Impact of Agroforestry Wine Production. Author's own work.

Realms of Deep Leverage	Impact of Agroforestry Wine Production
re-structure	• Creating an openness towards implementation of novel production patterns through agroforestry (alternated pruning patterns, use of green waste, benefits of extensive management, draught resistance, soil improvement, increased biodiversity etc.). • Enforcing and stabilizing local distribution patterns (increased sales through tourist information and on farms).
re-connect	• Reestablishment of a connection between production origin and consumer through spatial proximity of agroforestry vineyard and wineries, as well as educational work from the producers. • Increased attention of external winemakers and governance institutions.
re-think	• Annual change in management induces a reciprocal learning process about agroforestry winemaking. • Contrasting the ordinary wine production, the winemakers appreciate the agroforestry site and rethink their way of production, aiming at further sustainability transformation in the future.

It was apparent that the winemakers do see advantages regarding sustainability and mitigating the challenges regarding social, economic and ecological sustainability, implied in labour cost struggles and weather extremes. Meaning there is an understanding of the agroforestry system's advantages compared to the winemaker's regular parcels. Yet the agroforestry system was not favored to be extended in the future for three reasons. First, the existing system was not tailored to the wine production patterns so that forestal byproducts could be made use of. Second, the farmers remained unassertive to whether the climate change experienced in recent years would remain permanent. And third, the present agroforestry site was sufficiently integrated as a narrative supporting the individual ways of production and product sales with the notion of sustainability.

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