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Catalogue of Ecosystem-based Adaptation Approaches and transition pathways in the Alpine Space

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RESPOnD AT A GLANCE

Small-scale Alpine vineyards represent a remarkable blend of ecological integrity, cultural heritage, and economic significance. Situated within distinctive landscapes and microclimates, these vineyards are increasingly vulnerable to the impacts of climate change and shifting environmental conditions.

Rising water scarcity, drought stress, and extreme weather events are contributing to a decline in wine quality and threatening the long-term viability of viticultural practices. This poses a serious risk to traditional cultivation methods that have shaped regional identities and supported local economies for the past generations.

In response to these changes, the RESPOnD project seeks to collaboratively develop Ecosystem-based Adaptation (EbA) strategies and sustainable development pathways with winegrowers and policymakers. By validating EbA approaches in specific pilot areas and disseminating practical knowledge, RESPOnD aims to foster climate-resilient management and governance within Alpine Wine Orchards (AWO).

In particular, the present report provides the reader further insights regarding the various EbA approaches existing in the Alpine vineyards.

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List of Acronyms

AS	Alpine Space
AWO	Alpine Wine Orchard
CC	Climate Change
DAC	Districtus Austriae Controllatus (Austrian designation of origin for wine)
EbA	Ecosystem-based Adaptation
ES	Ecosystem services
EU	European Union
EUSALP	EU Strategy for the Alpine Region
LL	Living Lab
NGO	Non-Governmental Organization

1. Introduction

Climate change is exerting unprecedented pressure on traditional agricultural systems, particularly in vulnerable and sensitive regions such as the Alpine Space. Alpine Wine Orchards (AWOs), a hallmark of the Alpine cultural landscape, are characterized by small-scale, steep-slope viticulture with low levels of mechanization. While they produce high-quality wines and provide essential ecosystem services (ES) such as erosion control, biodiversity conservation, and cultural heritage preservation, they are increasingly under pressure from climate-related risks, high labour costs, land abandonment, and competition from intensive viticulture. Without coordinated and adaptive responses, their ecological and socio-economic sustainability is at risk.

In the RESPOnD project, AWOs are identified as small-scale, often terraced vineyards that, although limited in mechanization, contribute significantly to biodiversity, landscape preservation, and rural vitality. They are important not only for wine production but also for promoting tourism, creating jobs, and preserving local traditions and communities. In the framework of RESPOnD, we aim to consider all aspects of AWOs with the clear objective of supporting them through knowledge of Ecosystem-based Adaptation (EbA) and by empowering winemakers to adapt to climate change (CC). This specific combination of small scale, traditional practices, and strong community embeddedness may be the very reason why AWOs contribute so strongly to biodiversity, landscape preservation, and the vitality of rural areas.

In this context, the RESPOnD project aims to strengthen the climate resilience of AWOs by promoting EbA strategies that leverage nature-based solutions to reduce vulnerability and enhance sustainability. By jointly mapping ES, co-developing adaptive strategies through Living Labs (LLs), and transferring knowledge via digital tools and policy guidance, RESPOnD creates a holistic and scalable framework for future-oriented viticulture in the Alpine region.

Transnational cooperation is essential to address the shared climatic and socio-economic challenges that transcend national borders and to co-create solutions that are locally rooted yet widely replicable. The RESPOnD approach aligns with key European policy frameworks such as the EU Green Deal, the EU Strategy for the Alpine Region (EUSALP), and the Nature Restoration Regulation, positioning the project as a driver of integrated, resilient, and nature-based regional development.

The project aims to test ways to allow Alpine vineyards to adapt and be more resilient, in seven pilot areas across five countries (i.e., AT, DE, FR, IT, SI). The testing will be carried out in the form of LL implemented in three phases. This document provides a basis for better understanding EbA approaches in different areas and thus serves as a valuable resource for stakeholder involvement and collaborative development within the project.

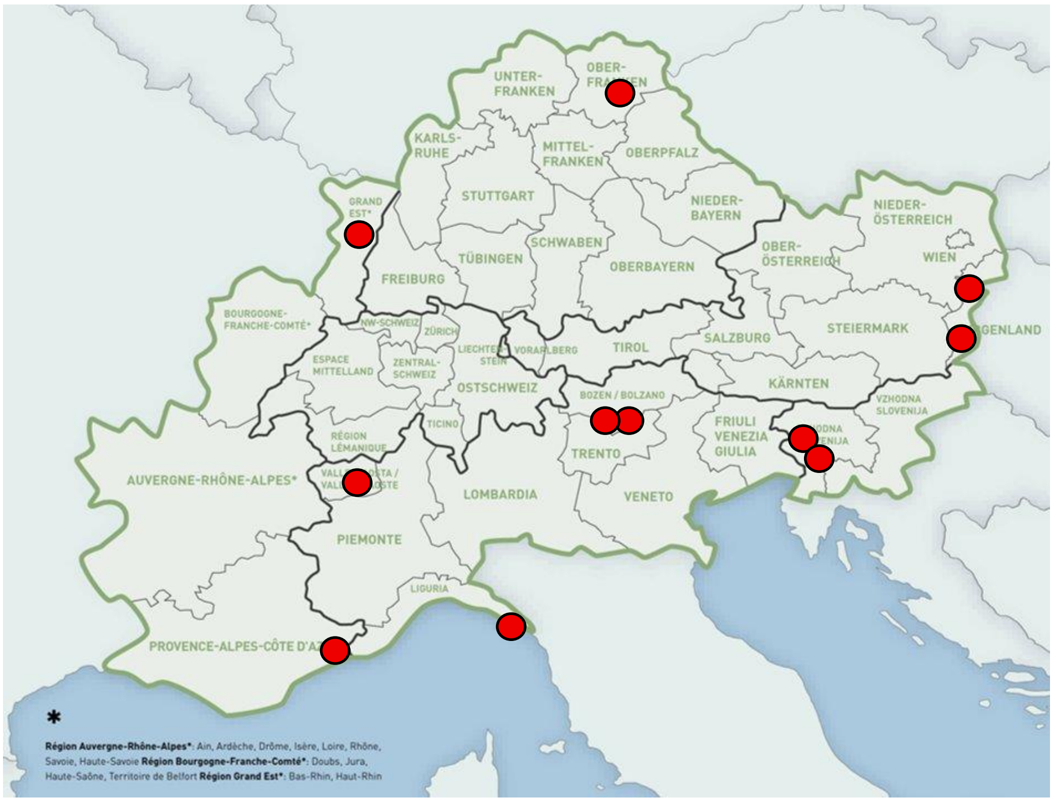

Figure 1: Project partners in RESPOnD project within the Alpine Space cooperation area.

Objective of the catalogue of EbA approaches in the context of the RESPOnD project

This report provides an overview of the current conditions, challenges, and potential for climate resilience in AWOs across the partner regions. It reviews relevant literature on EbA in the project's pilot areas, identifying climate-related vulnerabilities and assessing the ES provided by AWOs. The findings form a basis for the second round of LLs in the RESPOnD project and support transnational efforts to co-develop, test, and scale up EbA solutions. The document is designed for project partners but is also valuable for stakeholders and practitioners working in the wine sector seeking ecosystem-based approaches, with additional data provided in the annexed factsheets.

The role of EbA approaches in increasing the resilience of wine-growing areas

EbA is an emerging nature-based strategy that uses biodiversity and ES to help communities adapt to the adverse effects of climate change[48]. In the context of viticulture, EbA approaches offer innovative and cost-effective solutions to enhance the resilience of wine-growing areas, particularly in vulnerable Alpine regions. Measures such as maintaining landscape heterogeneity, restoring terraces and dry-stone walls, promoting soil cover and biodiversity, and integrating agroecological practices contribute to buffering climatic extremes while preserving cultural landscapes. The RESPOnD project promotes the co-design and testing of EbA solutions through LL and pilot actions in the field, ensuring that adaptation pathways are not only scientifically sound but also socially accepted and practically feasible. EbA thus serves as a bridge between ecological sustainability and economic viability in adapting traditional viticulture to future climate conditions.

1.1. Pilot areas

1.1.1. Alto Adige / Südtirol, Italy

South Tyrol, also known as Alto Adige in Italian and as Südtirol in German, is an autonomous province in northern Italy, nestled within the heart of the Alps at the border with Austria and Switzerland. The region is characterised by a unique alpine landscape, which includes deep valleys, steep mountain peaks reaching up to 4,000 metres above sea level, and a diverse mix of geological formations. This diversity contributes to a rich mosaic of natural ecosystems and cultural landscapes: the region is predominantly covered by forests, permanent and alpine grasslands, and sparsely vegetated areas, rocks and glaciers at the higher elevations. The valley floors are often intensively used for permanent cultivations.

In particular, the wine region is characterized by a small-scale and diversified structure. Over 5,000 individual winegrowers manage around 5,800 hectares, cultivating more than 20 different grape varieties adapted to various soils and climatic conditions. This diversity requires a high level of knowledge and expertise, built on a long-standing tradition and history. Still today, viticulture plays a key role in shaping the local identity and heritage and is an important part in the regional economy.

Compared to other agricultural regions facing the challenges related to rural abandonment and land degradation, South Tyrol keeps attracting the interest of the younger generations, mainly due to the stable and promising economic situation. Tourism is another central attribute, particularly in the form of eco and agrotourism linked to the local wine and the landscape heritage.

Despite this flourishing environment, small-scale viticulture faces many threats linked to climate change. Indeed, changes in precipitation and temperature regimes negatively impact the cultivation and long-term sustainability of important local varieties such as Pinot Blanc, Sauvignon Blanc, Gewürztraminer, Chardonnay, Pinot Noir, and Schiava. Through, Eurac Research and Laimburg Research Centre will particularly focus on water management in South Tyrol by engaging with stakeholders, testing new instruments to improve water use efficiency within the vineyards, and sharing knowledge with winemakers, producers, consortia or public agencies.

1.1.2. Cinque Terre, Italy

Established in 1999, the Cinque Terre National Park (5TNP) is a public authority directly under the jurisdiction of the Italian Ministry of the Environment. With its 3,868 hectares, located in the province of La Spezia, the 5TNP is one the smallest National Park in Italy, but also the most densely populated: about 3.500 inhabitants distributed in the villages of

Riomaggiore, Manarola, Corniglia, Vernazza, and Monterosso. The area is part of the World Heritage Site "Portovenere, Cinque Terre and the islands Palmaria, Tino and Tinetto", inscribed in 1997. In the same year it was also established the Marine Protected Area, managed by 5TNP.

Here, over more than a thousand years, man has transformed steep slopes into cultivable strips (the ciàn), supported by thousands of kilometers of dry-stone walls, creating a unique, heavily man-made landscape. Over the past 10 years, it has become a popular destination for tourists who come from all parts of the world to admire the unique and special landscapes.

The National Park aims to set actions and strategies to preserve biodiversity, reduce hydrogeological risk, and increase economic benefits from rural activities while maintaining local agriculture active in a sustainable way.

5TNP is the leading and coordinating beneficiary of the Stonewallsforlife (LIFE18 CCA/IT/001145) project, which aims at repairing dry-stone walls and ensuring their long-term maintenance, to protect the territory and its inhabitants against the effects of extreme weather events, which fits perfectly into the type of actions and best practices that the RESPOnD project wants to put in place for climate change adaptation in Alpine vineyards.

In this context, RESPOnD can further develop local actions to enhance the climate resilience of extensive vineyard ecosystems, and the valorisation of cultural and traditional heritage.

1.1.3. Südburgenland, Austria

Südburgenland, a traditional winegrowing region in southeastern Austria near the Hungarian border, is defined by its family-run vineyards, historic *Kellerstöckl* wine cellars, and a diverse cultural landscape shaped by centuries of sustainable land use. The region's gently rolling hills form a rich mosaic of vineyards, meadows, forests, and small-scale farms. As part of the Eisenberg DAC, Südburgenland is especially renowned for expressive Blaufränkisch and crisp Welschriesling, as well as the unique and culturally significant Uhudler wine.

Viticulture plays a central role in both the identity and economy of the region. However, winegrowers are increasingly challenged by climate change, including drought, shifting precipitation, extreme weather events, and heat stress. In response, many are adopting adaptive techniques such as planting new grape varieties, using cover crops, installing hail protection, and adjusting harvest times.

1.1.4. Vipavska dolina, Slovenia

The Vipava Valley, located in western Slovenia between the Nanos and Karst Plateaus, is a renowned winegrowing region within the Goriška statistical area, encompassing the municipalities of Ajdovščina and Vipava[1]. Its mild Mediterranean climate, fertile soils, and the

[1] In Vipava Valley there are three municipalities: Vipava, Ajdovščina and Nova Gorica. But RRA ROD only covers

meandering Vipava River create ideal conditions for viticulture, which has shaped the valley's landscape and identity for centuries. Family-run wineries produce both indigenous varieties such as Zelen and Pinela, as well as internationally recognized wines, making viticulture a cornerstone of the local economy and a key driver of tourism.

The valley is also a hub of sustainable farming, biodiversity conservation, and creative rural development. However, winegrowers and farmers are increasingly confronted with challenges such as climate change, water management issues, rural depopulation, and ageing populations. Investments in green technologies, innovation, and cross-border cooperation with Italy are seen as vital for ensuring resilience and long-term sustainability.

As part of the RESPOnD project, the Vipava Valley will serve as a pilot area focusing on climate-resilient viticulture and integrated landscape management. Building on EU projects like ECOVINEGOALS (Ecological Vineyards Governance Activities for Landscape's Strategies, Interreg ADRION 21-27), VISFRIM (Hydraulic Risk Management for the Vipava River Basin and Other Cross-Border Basins, Interreg Italia-Slovenija 21-27), or GREVISLIN (Green infrastructure for the conservation and improvement of protected habitats and species along rivers, Interreg Italia-Slovenija 21-27), as well as on local climate adaptation strategies, the project will use LL to foster dialogue among winegrowers, future wine experts (students), farmers, municipalities, and other stakeholders. The aim is to develop ecosystem-based approaches, test practical solutions, and strengthen collaboration for a sustainable and vibrant future of winegrowing in the valley.

1.1.5. Franken, Germany

The Franconian wine region in north-western Bavaria is one of Germany's most distinctive viticultural areas, shaped by the Main River and surrounded by the low mountain ranges of Spessart, Odenwald, Rhön, Hassberge, and Steigerwald. Characterised by a transitional climate with hot summers, cold winters, and low annual precipitation, it is among Bavaria's driest regions—posing increasing challenges for local viticulture.

Viticulture has deep roots in Franconia, particularly on the steep slopes along the Main River. The region is marked by small, family-run vineyards that form a fragmented yet culturally rich landscape. Silvaner is the emblematic grape variety, traditionally bottled in the iconic Bocksbeutel, symbolising the quality and heritage of Franconian wine. Beyond its agricultural role, viticulture significantly contributes to the regional economy, tourism, and identity.

Climate change is threatening this legacy through prolonged droughts, late frosts, and increased water stress, disrupting grape development and vineyard health. As a RESPOnD pilot area, the Franconian LL will focus on developing and testing ecosystem-based solutions for climate-resilient viticulture, with particular emphasis on water availability. Building on local knowledge and practices such as cover cropping, the project will foster collaboration

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the first two municipalities – Vipava and Ajdovščina. Nova Gorica is under different regional development agency, and that is why we only talk about Vipava and Ajdovščina.

between winegrowers and researchers to ensure the long-term sustainability of this historic wine region.

1.1.6. Ballons des Vosges, France

The Ballons des Vosges Regional Nature Park is located in the heart of the Vosges mountains in northeastern France. The eastern foothills of the park are covered by vineyards, covering approximately 5,000 hectares, under the AOC Vins d'Alsace appellation.

The park's vineyards are located in a landscape known as the “collines sous-vosgiennes” (foothills of the Vosges). Most of these vineyards are planted on slopes of varying steepness, and some are located on hillsides with a Grands Crus classification. They are operated by several thousand wine-growing businesses, most of which process their own production and sell it directly and through local distribution networks. The villages are numerous and densely populated, and tourism, including wine tourism, is an important activity. Most wine-growing practices are conducive to biodiversity, but their continuation depends on the economic health of the sector. In addition, the very specific soil and climate conditions may in future represent a weakness for the sustainability of these crops, particularly due to very low rainfall.

The terraces found in many vineyard plots contribute to high-quality production and have significant environmental externalities (biodiversity, landscape, water and soil quality). They are generally supported by networks of dry-stone walls, but their maintenance and restoration face obstacles linked to a fragmented stone value chain: availability and cost of materials, economic motivations of winegrowers, implementation costs, legal issues, etc.

Financial support mechanisms for the renovation of dry-stone walls already exist at several levels (municipal, departmental, regional) but remain insufficient in view of the needs. Through the RESPOnD program, the PNRBV aims to contribute to the (re)structuring of a local dry-stone value chain that supports agroecological practices and the resilience of Alsatian vineyards.

1.1.7. Valle d’Aosta, Italy

The Aosta Valley, Italy’s smallest region, is characterized by a predominantly mountainous landscape, with the exception of a limited flat area along the valley of the Dora Baltea river, where the few lowland vineyards are concentrated. Out of a total area of approximately 3,250 km^2, only about 400 hectares are dedicated to viticulture. Of these, 95% are located on hilly or mountainous terrain, while only the remaining 5% extends across the plains near the river.

Viticulture in this region is often described as “heroic”, a term that aptly captures the challenges of growing vines in such a difficult environment: steep slopes, rugged soils, high altitudes, and conditions that make mechanization impossible. This requires hard manual labor, carried out on terraces supported by dry-stone walls, which are essential to make even the steepest areas cultivable. Despite its small size, the Aosta Valley boasts extraordinary environmental diversity. Vineyards are found at various altitudes, from the valley floor up to 1,200 meters, as in the area of Morgex and La Salle, one of the highest wine-growing areas in Europe. This mosaic of microclimates, exposures, and elevations fosters a highly complex wine production. The climate of the Aosta Valley is generally dry and well-ventilated, with low rainfall and significant temperature fluctuations between day and night. These conditions allow for optimal grape ripening, preserving aromatic integrity and giving the wines freshness, elegance, and longevity. The soils, which vary greatly in geological origin, further enrich the uniqueness and typicity of the wines produced.

One of the distinctive features of viticulture in the Aosta Valley is its great varietal biodiversity. Alongside international grape varieties like Pinot Noir, Nebbiolo, and Syrah, the region is home to rare or exclusive native varieties such as Petit Rouge, Vien de Nus, and Cornalin. The Valle d'Aosta / Vallée d'Aoste DOC appellation, which covers the entire regional territory, is organized into geographical subzones and varietal denominations to highlight this rich ampelographic heritage. As for vine training systems, there is no single model mandated by the DOC regulations. However, in less steep areas, modern systems like Guyot and cordon spur are preferred, while in more challenging terrains, traditional forms adapted to local conditions are used, such as pergolas or low-trained rows. All systems aim to facilitate manual labor, reduce erosion, and respect environmental balance.

In conclusion, viticulture in the Aosta Valley is a virtuous example of integration between tradition, territory, and biodiversity, capable of producing authentic wines with great personality.

2. Methodology of the EbA literature review

This section outlines the methodology applied to review the literature on EbAs in viticulture, including a description of search strategies and the inclusion/exclusion criteria used for selecting relevant literature. These elements were jointly agreed upon and developed in collaboration with all project partners involved in the RESPOnD project.

In the initial phase of the review, all project partners agreed that each would be responsible for conducting literature searches relevant to their respective geographical areas. While the primary focus was placed on literature connected to the specific pilot areas, the search was not confined strictly to the local level. Instead, the scope was broadened to encompass the national context of each partner country in order to capture relevant research and documentation that could be applicable to the pilot sites.

The search included not only peer-reviewed and formally published academic literature, but also extended to grey literature, which is often an important source of practical and localized knowledge. Grey literature was defined here as including unpublished studies, technical reports, internal documents, working papers, government and NGO reports, and other non-commercially published material. This inclusive approach was aimed at gathering a comprehensive body of knowledge, including resources that may not yet be widely disseminated or formally published but hold significant relevance for the project objectives.

The literature collected by each partner pertains to the seven pilot areas of the RESPOnD project and focuses specifically on ES and EbAs, as explored or mentioned within the reviewed materials. In order to ensure that the most relevant, useful, and practical information was identified, the literature review was carried out in two distinct steps:

1. **Collection Phase**:

Each project partner searched for and compiled literature using a variety of sources. This included national, regional, and local library databases (including university libraries), online repositories, institutional collections held by municipalities, development agencies, environmental organisations, and similar bodies. The goal of this phase was to compile as broad a selection of relevant materials as possible into a single shared document.

2. **Analysis Phase**:

In the second step, the gathered literature was systematically analysed using a standardized evaluation form (see Annex 1). This allowed for consistent comparison across all materials and partner regions. During this process, literature that did not align with the aims of the RESPOnD project or failed to meet the agreed criteria was excluded. The following main criteria were applied during the detailed evaluation phase to assess the relevance and quality of the collected literature:

- number of EbA approaches described in the source,
- geographic scope of EbA implementation (e.g., regional, national),
- macro-category of each EbA (e.g., cultural, environmental, agronomic),
- specific field of application of the EbA (e.g., plant management, soil conservation, water use, biodiversity, landscape preservation, cultural heritage, climate adaptation, yield stability),
- name or type of the EbA approach (e.g., flower strips, clone selection, green manuring, etc.),
- scale at which the EbA is applied (e.g., vine-level, vineyard-scale, landscape-level),
- ES referenced, along with a specification of which ES are addressed by the approach,
- type of motivation or incentive behind the implementation of the EbA (e.g., political directive, research-driven initiative, environmental policy, market-based instrument, etc.).

Following the successful first step, where the PPs prepared a comprehensive list of relevant literature, a detailed analysis was carried out according to the defined criteria.

3. A framework for Ecosystem-based Approaches in Alpine viticulture

3.1. Macro categories

The content gathered from the literature has been first analysed by focusing on the macro-categories. As shown in the graph below, the collected EbAs have been classified into three macro-categories: agronomic, environmental, and cultural. The majority of the analysed literature describes EbAs related to the environmental or agronomic domains, while cultural EbAs are mentioned only rarely.

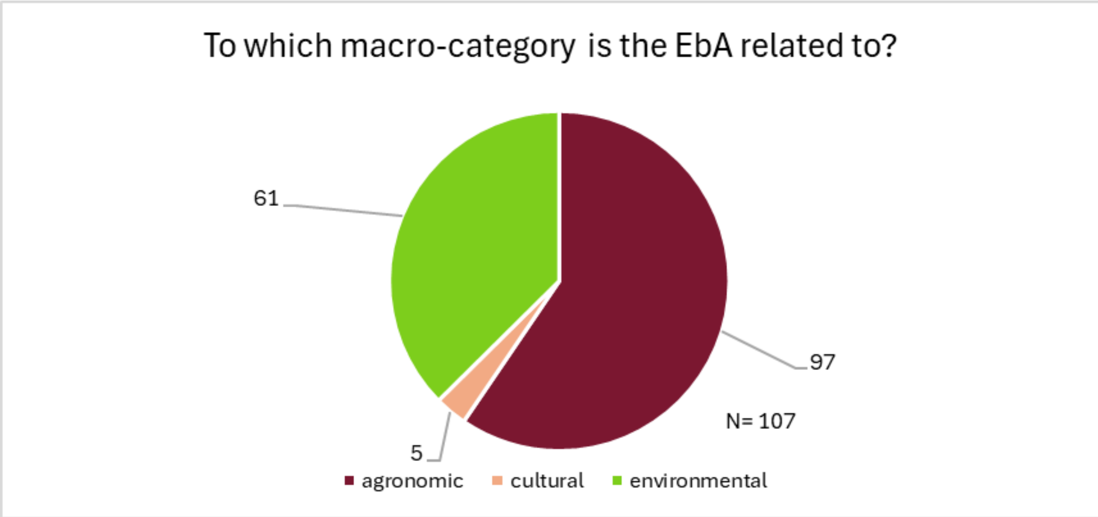

Figure 2: Graphical representation of the distribution of the analysed literature into macro-categories.

Most approaches fall within the agronomic and environmental domains, which focus on improving crop conditions and managing the surrounding ecosystem in the Alpine area. For instance, cover crops represent a key agronomic EbA, delivering ES like erosion control, improved soil health, enhancing biodiversity, and protecting the landscape beyond the vineyard itself. Similarly, but categorized differently, the greening of fallow land is an environmental EbA that enhances biodiversity, protects soil, and also conserves the landscape beyond the vineyard itself. The cultural category, even though the smallest, is an important dimension of EbAs. The example of cultural EbA is the maintenance of dry-stone walls. In a cultural sense, they provide ES of the preserving the cultural landscape and aesthetics. It's important to note that these categories are not mutually exclusive; a single EbA, such as dry-stone walls, provides cultural value while also delivering significant environmental benefits, such as erosion protection and biodiversity enhancement.

3.2. Fields of action

A further categorisation of EbAs was based on their field of action. Although there are several categories, their principal focus is clearly distinguishable. The fields of action include soil, water, plants, biodiversity, landscape, and cultural heritage. In relation to soil, EbAs address soil health as well as microbial and enzymatic activity. In the case of water, the emphasis is on availability. For plants, the main concern is yielding stability under changing climatic conditions, while for the landscape the focus lies on the preservation of vineyards on slopes and terraces, thereby preventing erosion and landslides. Biodiversity is also an important field of action, approached from different perspectives. Finally, cultural heritage provides another dimension, which, although distinct, remains highly relevant for the inhabitants of these areas.

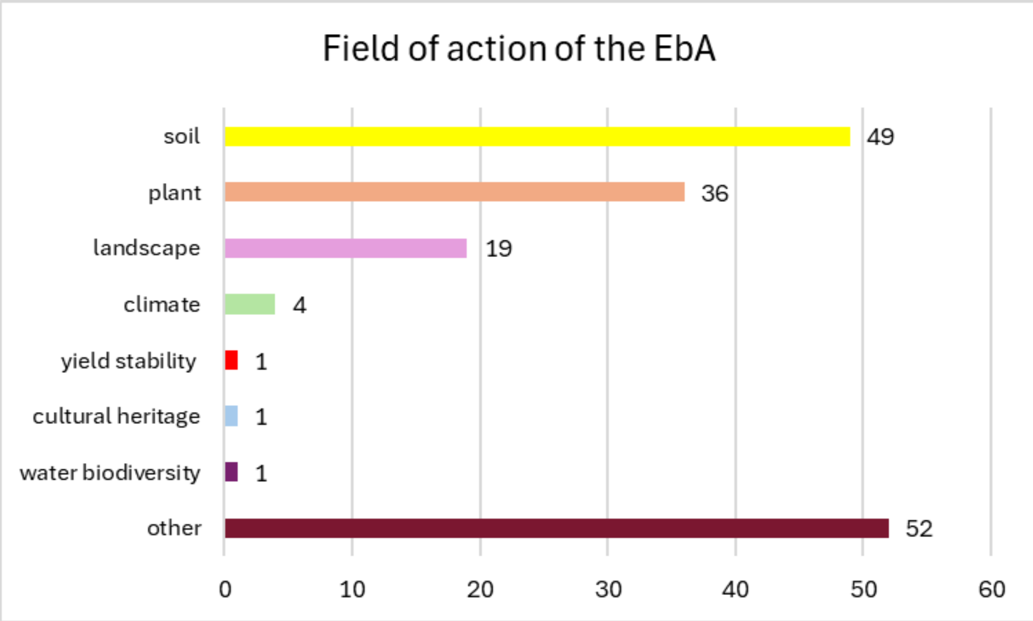

Figure 3: Graphical representation of the content of the analysed literature based on the field of action of EbA.

3.3. Spatial scale

The EbAs were also categorised according to spatial scale. At the vine level, they focus specifically on practices applied to individual vines, aimed at improving plant production. At the vineyard level, they address the management of the vineyard as a whole, targeting aspects such as soil, water, and other resources, which indirectly support vine growth. At the landscape level, EbAs extend beyond the vineyard itself and include the surrounding land uses, addressing wider environmental interactions and functions. It should be noted that these categories may overlap to some extent.

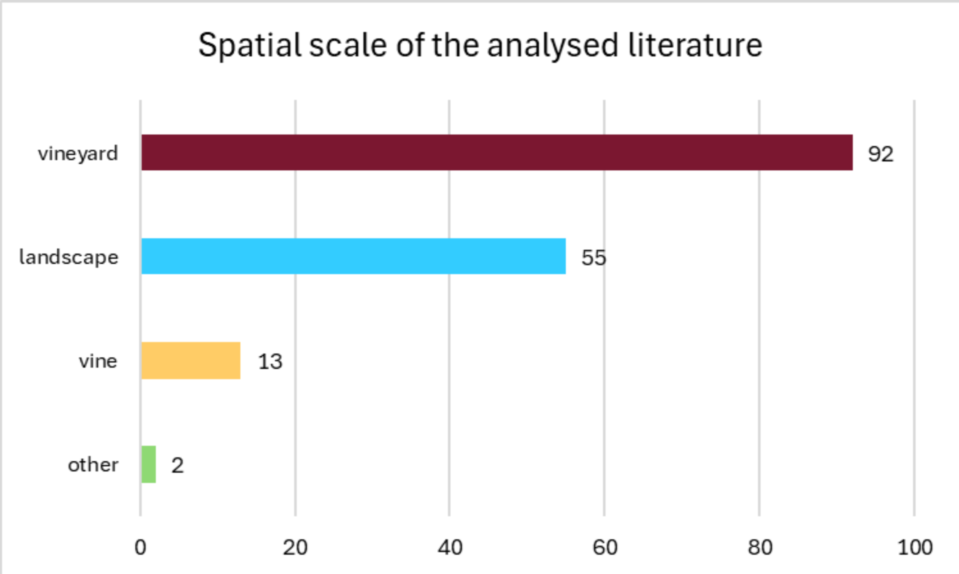

Figure 4: Spatial scale of the analysed literature (other: orchard (1), slope (1))

3.4. Ecosystem services

As in the previous section, EbAs were divided based on the field of action. Such division can lead to vast EbAs in Alpine viticulture being overlooked. A single EbA can provide more than one ES at once. To facilitate comprehension, a list of EbAs with their corresponding ESs, grouped by field of action, was created.

Field of Action	**Ecosystem-Based Adaptation (EbA)**	**Key Ecosystem services**
Soil	Cover crops / Inter-row greening / Green manuring	soil health & fertility[2,3], erosion control[3,4], water retention[5], carbon sequestration[3,5], weed control[2], biodiversity & pollination[5]
	Fallow land greening	soil health & fertility[6], biodiversity, nutrient cycling[3], erosion control, carbon sequestration
	Mulching / Soil cover with organic material	soil health[3], water retention[5], weed control, humus production[2]
	No tillage / Reduced tillage	soil health[3], water retention[7], erosion control[2], carbon sequestration

	Humus / Organic matter increase	soil fertility & health[3,8], water retention[3], nutrient cycling
	Soil amendments / Biochar / Compost	soil health & fertility[5], carbon sequestration[3], nutrient cycling, grape yield increase[5]
	Appropriate fertiliser amount	soil fertility[8], grape yield[5]
	Grazing by sheep/animals	weed control[5,9,10], soil health, fertilization
	Bio-engineering	erosion control[22], soil creep protection[2], landslide/hydrogeological risk mitigation[28,32]
Water	Vegetated buffer strips / Flower strips	water quality improvement[2,7], erosion control[11], habitats & biodiversity[12]
	Renaturalisation of runoff channels / gutters	erosion control[2,8], flood prevention, water quality, habitats & biodiversity
	Restoration of waterways / verges	water quality[8], habitats & biodiversity, flood prevention
	Drip irrigation / Resource-saving irrigation	water conservation[13]
	Drainage systems	erosion control[2], flood prevention, water retention
	Micro water storage / Water retention troughs	water retention & storage[8]
Plant	Land reorganisation / Consolidatio	crop production[6], learning & education[14]

	n	
	Biodynamic viticulture	soil health[3,5], habitats & biodiversity, grape quality[15]
	Canopy management & Pruning management	grape quality[2,16,17], grape yield, microclimate regulation
	New grape varieties & Drought-tolerant rootstocks	grape quality[3,18], grape yield[5,19,20]
	Adapted pest control	fungal disease control[2,5,17], pest control[3], grape quality[21], grape yield
	Vineyard relocation / reorientation	wine production[18], grape quality
	Harvest timing adaptation	grape quality[3,20], grape yield
	Nets against hail / sunburn	grape quality[3,18], grape yield
	Early-warning models for fungal pathogens	fungal disease control[18]
Biodiversity	Hedges / Isolated trees / Shrub planting	habitats & biodiversity[3,5,22], microclimate regulation, pest control, erosion control[9], landscape conservation[22]
	Perennial flower beds	habitats & biodiversity[23], pollination[5,24], pest control, landscape conservation[6], grape yield[2]

	Agroforestry	microclimate regulation[2,9], habitats & biodiversity, carbon sequestration, wood (material)
	Habitat creation (e.g., nesting boxes, specific structures)	habitats & biodiversity[2,22], pest control, pollination
	Use of perennial plants for diverse fauna	habitats & biodiversity[24], pest control[3,24,25], pollination
	Use of aromatic plants for intercropping	pest control[26], pollination
	Predator mite monitoring / Arthropod surveys	pest control[23,25]
Landscape stability	Protected forests / Vegetation cover	erosion control[3,4,27], flood/runoff prevention[13], habitats & biodiversity[28], carbon sequestration[7]
	Terrace restoration & New terracing systems	erosion control[29–31], landslide/hydrogeological risk mitigation[22,28], cultural heritage[6,22,28], aesthetics
	Earth filling / Erosion control measures	erosion control[8,29], landslide/hydrogeological risk mitigation[28]
Cultural heritage	Dry-stone walls	erosion control[2,30], habitats & biodiversity[2,22,24,30], risk mitigation[2,22], cultural heritage[8,22,30,33], aesthetics

The extensive list of EbAs demonstrates that a multitude of solutions exist to address the challenges facing Alpine viticulture. It is also possible to observe that the majority of the approaches are addressing resilience to climate change (resilience to rising temperatures, droughts, extreme weather events, erosion, etc.) while simultaneously supporting the social and economic vitality of rural areas. Thus, the EbAs are not only meant to protect natural ecosystems, but also to enable preservation and further development of the rural area.

3.5. Transition pathway

The transition pathway to EbAs for the wine sector involves a strategic shift from input-intensive agriculture to a regenerative, ecosystem-based model that builds long-term resilience and aligns with green market demands. The EbAs in Alpine viticulture is not only beneficial for climate change adaptation, but their implementation is also supporting the path towards the Sustainable Development Goals of the United Nations. They are addressing at least six SDGs out of seventeen.

SDG 2 (Zero hunger): By ensuring the long-term productivity and sustainability of viticulture, EbA contributes to food security and sustainable agriculture.

SDG 6 (Clean water and sanitation): Improved soil health and land management practices can increase water retention, reduce run-off, and protect water quality.

SDG 8 (Decent work and economic growth): Building resilient viticulture systems secures livelihoods and economic stability for wine producers and local communities.

SDG 12 (Responsible consumption and production): EbA promotes more sustainable and less input-intensive farming practices.

SDG 13 (Climate action): EbA is a strategy for climate change adaptation and can also contribute to mitigation through carbon sequestration in soils and biomass.

SDG 15 (Life on Land): EbA focuses on protecting, restoring, and sustainably managing terrestrial ecosystems, promoting biodiversity within and around vineyards.

While significant overlaps exist, the agronomic category primarily supports SDG 2 and 12 by enhancing sustainable production, whereas the environmental category is fundamental to achieving SDG 6, 13, and 15 through ecosystem protection. The cultural category strongly aligns with SDG 8 by reinforcing the economic and social value of heritage landscapes.

As introduced in section XY, the project classified EbAs in Alpine viticulture of the pilot areas into three macro-categories. The agronomic macro-category encompasses farming practices used in the vineyard. The agronomic transition pathway should address moving from conventional methods to a more sustainable, data-informed, and regenerative approach. Thus, the pathway would lead from an input-intensive model focused on maximizing short-term yield, often relying heavily on chemical fertilisers, pesticides, and reactive management, to a regenerative and precision-based system. The goal is to adopt practices that improve soil health, such as no-tillage and cover crops, and to integrate technology for precision irrigation and early warning systems. This leads to more efficient resource use, reduced environmental impact, and a more resilient, self-sustaining vineyard.

The environmental macro-category encompasses the broader ecosystem and infrastructure surrounding vineyards. The transition pathway is a fundamental shift from viewing the vineyard as a monoculture to recognizing it as an integral part of a complex, biodiverse landscape. Thus, a pathway would lead from sole focus on the vineyard as an isolated production unit, with little consideration for the surrounding ecosystem and natural water cycles, to a holistic, ecosystem-based management approach. The pathway involves actively restoring and enhancing natural habitats through agroforestry, hedgerows, and ecological corridors.

Finally, the cultural macro-category focuses on the social fabric, knowledge systems, and historical heritage that define Alpine viticulture. The transition pathway involves an evolution of mindsets and community practices to embrace adaptation while preserving a rich cultural legacy. The pathway involves integrating new scientific knowledge with generational wisdom. It fosters community-based networks for sharing best practices, while also re-evaluating traditional regulations, which are sometimes very strict. This way would make it possible to adapt innovations, such as new varieties, without losing regional identity.

Even though some EbAs would seem quite straightforward, some elements should be considered for the successful implementation of a specific EbA. Thus, in the next part, the hindering and success factors will be presented and discussed. Many EbAs share common hindering and success factors; thus, a common consideration was made.

Factors hindering the implementation of EbA measures

Efficient implementation of Ecosystem-based Adaptation (EbA) requires recognizing and addressing the hindering factors that may limit success. Ideally, these challenges should be overcome; however, at the very least, there must be awareness of their presence. Such barriers are primarily linked to environmental, social, and economic considerations, each of which influences the extent to which EbA measures can deliver sustainable outcomes.

Economic and labour constraints

The viticulture sector is facing significant labour force challenges[23]. This is largely due to the highly labour-intensive nature of work and the financial compensation that often does not match the demands of the occupation[9,23]. This disparity causes a decrease in the workforce pool, as people often decide on alternative occupations[23]. In turn, it can present a big issue for implementing many of the EbAs, as they generally require more labour[10]. Many EbAs require more labour because they substitute large-scale mechanization and chemical applications with hands-on, precision-based tasks. This often involves manual work such as managing cover crops, maintaining new habitats, or restoring landscape features such as terraces.

This issue is even more pronounced in the case of the steep-slope vineyards, which are common in Alpine viticulture. Compared to flat-lands vineyards, the management of those vineyards can be much more labour intensive and cost-intensive[2,9,34,35].For example, in the Moselle-Saar region, viticulture on steep slopes requires a high input of labour and costs, and their management can be four times higher in working input compared to flat regions.[36]

Unfortunately, in some places, as steep-slope vineyards cannot provide adequate profitability, it leads to their abandonment[6,8,28,35]. Such an example can be observed in the Middle-Rhine Valley and Mosel, where viticulture on steep slopes has significantly declined in recent decades due to insufficient profitability[35]. One would perhaps argue that the problem could be solved by increasing the price of the product; however, it is not so simple to pass the increased costs to consumers. Market forces sometimes require a specific price for a product; thus, it is hard to simply increase the price of a product to cover increased costs, although justified[9]. Consumers may opt for cheaper competing products, leaving winemakers of higher-priced wines with insufficient funding for future production seasons1.

Although the development of better machinery could offer a partial solution, it also increases expenditures, which not all viticulturists can afford[22,34]. For small vineyards, the use of machines, even when possible, is extremely costly and requires technical solutions tailored to their limited plot sizes[22]. The example can be experienced in the Aosta Valley, where the vineyards are located on steep slopes, in small plots, and sometimes on terraces, making the use of mechanization difficult or impossible. Thus, a high manual labour input is required, which consequently brings high costs. Public assistance, however, can play a crucial role. Public aid for purchasing agricultural machinery and equipment can effectively reduce hourly costs, thereby providing support to both small and large wine estates.

Without such support, the high production costs could lead to a decline in viticulture. The abandonment of viticultural land can be associated with some concerns. Consequently, cultural heritage and traditional landscapes could disappear[24]. It could also result in a loss of the positive externalities it provides, such as tourism benefits.

On the other hand, a focus on greater profitability can sometimes lead to production intensification, which has its own set of potential environmental impacts[37]. Over time, certain intensive practices might affect the local environment by negatively impacting water quality, reducing biodiversity, or harming surrounding flora and fauna. This approach, while economically motivated, may challenge the long-term ecological balance of an area; therefore, it is necessary to support the implementation of EbAs.

Knowledge gaps and mindset barriers

The viticulture sector faces significant challenges in implementing EbAs, largely due to the pervasive impacts of climate change itself and various socio-economic and knowledge barriers[37]. Although EbAs are meant to be a sustainable way to build resilience to climate change, climate change can also be a hindering factor. Increasingly frequent dry periods and high temperatures increase environmental stress, which in turn impacts both natural and agricultural ecosystems[38]. Such weather occurrences can, for example, cause a poor ripening of grapes or sunburns[9]. In addition, altered pest dynamics were observed, which led to increased pest populations and new invasive species[37]. On the other hand, climate change also increased the incidence of hailstorms, which can cause damaging damage to grapevines, and torrential rains[13]

As climate events influence grapevine development, they should be well understood. Furthermore, the specifics of the EbAs should also be understood. The application of some EbAs without adequate knowledge could, in some cases, also cause damage to the vineyard, which is the opposite of the goal of EbAs[2,15,39]. Such an example could be an implementation of cover crops, which, although beneficial, could present to vines a competition for water in times of drought, thus causing a decrease in yield[39].

Without adequate resources, it is hard to implement EbAs[2]. Knowledge could indeed be crucial for a good response, which some of the viticulturists might lack of[5,20]. Sometimes this lack of knowledge is caused by viticulturists' lack of time and even money to gain new knowledge[9]. Especially smaller operations could lack resources like time and money. That could cause their unawareness of existing information and even funding opportunities[7].

Many traditional winegrowers may be hesitant to adopt long-term strategies, viewing new concepts as risky, as there might not be evidence for their functionality[40]. Furthermore, as some farmers lack successors and the future existence of their company is questionable, they tend to be more focused on the present, while not putting much focus on the future[8]. Another reason for not adopting new ways might be that something was done 'traditionally'[9] and they do not see a sense in changing. But perhaps, the reason for not adopting new methods might be because of uncertainty around the concepts, as they sometimes lack adequate proof; thus, viticulturists are sceptical if they will work[5].

Policy and institutional frameworks

Sometimes, there is an overly rigid legal and institutional framework that can negatively affect the development of adaptation capacities in the wine sector[8]. That is, there is a set of rules that require a specific way of doing something, while restricting innovative approaches, despite new challenges arising. Institutions often cannot effectively implement new tasks related to sustainable adaptation because they change slowly. Therefore, while policies can be changed, it takes quite a bit of time to conclude[20].

Furthermore, as EbAs can be, in some cases, cost-intensive[35], there is a need for financial support[9]. EbAs and other sustainable practices can indeed be costly. For example, rehabilitating traditional vineyard terraces, which serve as erosion control and biodiversity refugia, requires significant economic means[6]. Another example is the increased costs associated with implementing ecologically certified wine-making. That's why they might be perceived as unattractive by some farmers, acting as a barrier to adoption. Local authorities are encouraged to financially support organic farming to help cope with potentially lower productivity during transition periods.

Success factors

As mentioned, hindering factors should be overcome, and even though they are somehow troublesome, they should not demotivate EbAs implementation. The reason for this is that individual farmers and the larger group of people can gain many benefits.

Economic opportunities and diversification

Implementing EbAs, as already mentioned, could be cost-intensive but at the same time it can add some economic benefits. Sustainability and eco-friendly practices can be a strong marketing tool, especially for premium wines, improving image and potentially allowing for unique product positioning[9,10]. Sometimes, wines produced in such conditions can have higher prices, which could facilitate coping with the higher costs. Consumers are increasingly influenced by factors such as product origin and sustainable practices, which can lead to a greater willingness to pay a reasonable premium for wines from mountain vineyards, recognizing the effort involved in their production[41].

Furthermore, this could promote diversification as it adds value to rural tourism[42]. EbAs contribute to rural development by linking the wine sector with growing rural and thematic tourism[2]. The preservation of traditional cultural landscapes, such as steep-slope vineyards, is of significant importance to regional income due to their aesthetic appeal and value for tourism. Tourists expect and appreciate biodiverse landscapes with vineyards on steep slopes, rather than fallow land[24]. In addition to tourism, there could also be other streams of income. Such products, in the case of sheep weed grazing in vineyards, are sheep wool and meat[9,10].

Some EbAs could even lead to cost savings, as they help reduce machine use, lower fertiliser input, etc. An example is a measure such as minimum tillage[18]. Minimum tillage could, with increased organic fertiliser addition and improved soil vegetation cover management, contribute to saving time, labour, and money, while reducing carbon footprint.

Knowledge transfer and collaboration

As mentioned above, there is a critical need for effective knowledge transfer and awareness raising. Thus, various events, such as workshops and field excursions with the addition of educational materials aimed at both winemakers and the broader public, should be organized[12,43,44]. Furthermore, to increase credibility, the local stakeholders should be involved in knowledge transfer. One of the better ways to establish successful collaboration is through the common development of LLs[7].

Creating or leveraging cooperation models can address practical challenges such as machinery and workforce limitations, while also accelerating knowledge transfer. One of the examples can be found in Austria, where it is possible to rent equipment through machine cooperatives or agricultural machinery manufacturers (e.g., for a flowering strip mulcher) which has proven highly effective[43]. This allows multiple companies to use expensive equipment without an individual purchase, potentially streamlining consulting by linking it to equipment rental.

Technological advancement also helps with the implementation of EbAs[7]. Digital technologies and platforms[45] are increasingly used to monitor agrometeorological parameters, which can lead to improved vineyard management by more efficient use of resources[38]. In addition to that, there are decision support tools that can help assess the efficiency and economic impact of the changes in cultivation[7].

Policy alignment and financial support

One of the most important factors is finances[2]. The implementation of some EbAs can require significant financial investment. Thus, providing proper support is crucial to successfully implement EbAs[7,28]. The financial incentives and subsidies from local authorities and agricultural programs are crucial for supporting the transition to sustainable and organic farming[24]. Therefore, the existing agricultural policies should be aligned with the nature-based solutions agenda to be able to create significant socioeconomic opportunities[3].

To facilitate acceptance and implementation of EbAs, vineyards should be recognised as a multifunctional landscape that provides multiple ES[3,7]. The vineyards should not only be valued for grape production, but also for many other ES that they provide[3]. Therefore, to fully realize a vineyard's potential, a comprehensive and integrated perspective is needed instead of focusing on isolated factors. This approach can lead to the successful regeneration of the function of the vineyard and biodiversity[15].

One potential instrument to support the implementation of EbAs is Geographical Indications[3]. They can help with the implementation of EbAs and the further development of rural areas. However, clear goals and actions should be identified and integrated into their specification documents. Such integration could benefit both producers and consumers by promoting tailored local policies for nature-based solutions adapted to each unique combination of an area's climate, soil, terrain, and human traditions or simply put "terroir”.

4. Future outlook of Alpine viticulture and recommendations

How should the viticulture sector continue to become more sustainable? Alpine viticulture is a unique intersection of environment, culture, and economy[46]. Its specifics can enrich the environment in which it is placed, as well as the worldwide wine sector[35]. Climate change events cannot be controlled by humans, but could be mitigated[7]. There is a growing awareness among the public about their environmental impact, leading to more responsible actions[16]. There are tools to mitigate the impacts of climate change, but they still have to be better accepted among viticulturists in order to be implemented[9]. When implementing changes, it takes time for them to be widely accepted[40]. Thus, changes can be reached with an appropriate long-term plan that includes multiple parties who can contribute the necessary skills and knowledge (including local knowledge) to achieve the set targets.

Embrace site-specific solutions

Achieving environmental goals in the viticulture sector, particularly through EbAs, requires a nuanced approach that acknowledges the unique characteristics of each environment. There is no one-size-fits-all solution[8,40]. Each of the proposed EbAs should be examined for an environment in which they would be introduced[8]. Thus, the practices and technologies must be adapted to the specific local conditions, such as climate, site characteristics, soil properties, pests, irrigation methods, and the availability of local inputs[16]. There are examples of positive outcomes of particular EbAs in the environments where they were introduced, but perhaps in different environments the results might not be the same. As mentioned, the reason is that each environment has its specific characteristics, so it is challenging to predict the outcome[10]. It would be a reasonable path to support the creation of LLs or experimental sites, where the response in a specific environment would be observed[3,15]. Therefore, it is important to involve science to investigate EbAs in order to fill the knowledge gaps and create proper decision models for the farmers. This might also help with the greater acceptance of the EbAs.

This highlights the need for careful planning. For example, when introducing new plants, their suitability for the local environment must be confirmed[2]. Consequently, it is crucial to consult with a specialist before implementing a particular EbA. An expert will understand the specific environmental conditions, the details of the proposed EbA, and be able to anticipate potential issues.

Ultimately, an in-depth understanding of both the environmental context and the specifics of the EbA is essential for making informed decisions and achieve the best possible outcomes for a more sustainable viticulture sector[8].

Strengthen policy and financial support

Strengthening policy and financial support is crucial for the successful implementation and widespread adoption of EbAs in the viticulture sector, especially in the light of their potential for long-term benefits despite initial challenges[40]. Effective implementation of EbAs requires urgent action in four key areas: building evidence and assessment tools, strengthening national and local institutions, developing coordinated and evidence-based policies, and

increasing financing and its effectiveness. Coordinated policymaking and stable, dedicated financing are essential pathways for climate-resilient transformation in viticulture.
In some cases, the policies are too rigid and perhaps outdated, which inhibits the implementation of new EbAs despite the benefits[7]. National legislation and other instruments often fail to compel lower administrative levels to incorporate adaptation into spatial planning. Many regulations are not fully binding, reducing actual implementation. Local planners and politicians may also hesitate to implement adaptation activities if they lead to self-imposed restrictions or conflicts with other local interests.
The initial investment in new approaches can be costly; thus, appropriate subsidies should be offered for the implementation of an EbA and the provision of ES[40]. The implementation of adaptation measures is also often hindered by a lack of awareness of, or access to, existing support and funding opportunities, which are often too complex for individual farmers and smaller communities[36]. Therefore, it is necessary not only to provide appropriate subsidies, but also to inform those they are intended for appropriately.

Address labour and land management challenges

There is an urgent need for comprehensive policy and financial support, focusing on the re-use of abandoned land, streamlining land management, and attracting a new generation of viticulture workers. A key approach is to develop a proactive land policy that connects demand and supply for agricultural land, particularly for abandoned agricultural land[47]. This could be done through the creation of an agricultural organisation or collaboration with existing ones, which could help to address the land challenges.
For example, abandoned land could be allocated to new wine producers. Despite a decrease in interest in farming occupations, there are still people who would still like to work in this sector. Consequently, it is pivotal to identify effective strategies to engage with these people and develop models that would motivate them to pursue careers in agriculture[2]. One way to attract and motivate those viticulturists to keep on developing Alpine viticulture is with appropriate financial support. Yet there's more to it than that. Social agriculture is identified as a driving force for growth, ethical, social, and economic protection, and can attract young people by providing production opportunities, leisure, growth, and healthy living. It aims for social and labour inclusion and provides services in rural areas. Thus, the issue can be addressed from multiple perspectives, as focusing only on one might not be enough.

5. Conclusions

This analysis was set to examine and evaluate the EbA in mountain viticulture of the Alpine Space cooperation area. The research show that even though there are plenty of agronomic and environmental solutions, it is strongly intertwined with the cultural and economic context in which they are implemented. The classification into three macro-categories highlighted that generally it is not trivial to categorize EbAs, as they can fit in more categories at once.

It is important to recognize that an Alpine vineyard is not only an agricultural site, but a complex, multifunctional landscape. Thus, when implementing EbA, the focus should not only lie on technical implementation but also on cultural and economic aspects. Furthermore, this review underscores that building resilience in Alpine viticulture requires a holistic approach that integrates different perspectives. It is important to balance tradition with innovation, ensuring these iconic landscapes of Alpine viticulture can continue to thrive in a changing world.

While this review identified major trends and practices in the project pilot areas, some are scenario-based and require further research. Future studies would benefit from quantitative analyses examining the long-term benefits and economic costs of these practices. Additionally, research into effective knowledge transfer and the impact of various policies on EbA adoption is essential. Ultimately, there is no single solution. The future of Alpine viticulture lies in continuous and collaborative work that integrates scientific findings, local knowledge, and financial common sense. Through this holistic approach, these iconic landscapes will not only survive the challenges ahead but also leave a more sustainable and resilient legacy for generations to come.

Sources

1. Loose, S. & Strub, L. Wenig wasser, hohe kosten. *Der Deutsche Weinbau* 14–18 (2021).
2. *Deliverable T1.1.1. Document with Definitions, Criteria, and Methods for Selection of Demonstrative Viticulture Areas and Agro-Ecological Vineyards; Annex: 29 Best Agro-Ecological Practices*. https://ecovineroads.com/wp-content/uploads/2022/12/DT1.1.1_Annex_AgroEcological_Practices_list_final.pdf (2020).
3. Rusch, A. Nature-based solutions to increase sustainability and resilience of vineyard-dominated landscapes. *Basic Appl. Ecol.* **82**, 70–78 (2025).
4. Stanchi, S. *et al.* Effect of Soil Management on Erosion in Mountain Vineyards (N-W Italy). *Sustainability* **13**, 1991 (2021).
5. O'Brien, F., Nesbitt, A., Sykes, R. & Kemp, B. Regenerative viticulture and climate change resilience. *OENO One* **59**, (2025).
6. Wersebeckmann, V., Entling, M. H. & Leyer, I. Revegetation of vineyard terrace embankments: A matter of seed mixture and seeding technique. *J. Environ. Manage.* **317**, 115409 (2022).
7. *Guidelines for Climate Change Adaptation at the Local Level in the Alps*.
8. Niewind, J. Maßnahmenkatalog: Nachhaltige Klimaanpassung im Weinbau der Mittelmosel. (2023) doi:10.25353/UBTR-XXXX-0D69-E4C9.
9. Riekötter, N. & Hassler, M. Agroforestry Systems in Wine Production-Mitigating Climate Change in the Mosel Region. *Forests* **13**, 1755 (2022).
10. Schoof, N. *et al.* Sheep in the Vineyard: First Insights into a New Integrated Crop–Livestock System in Central Europe. *Sustainability* **13**, 12340 (2021).

11. *Biotopbausteine zur Förderung der Biodiversität in der Weinkulturlandschaft*. (2022).
12. Activities - Project aktivities. https://www.life-vinecos.eu/en/activities/index.html.
13. *Rapporto sul clima: Alto Adige 2018*. (2018).
14. Achtziger, R., Köstner, B. & Richert, E. DAS-Projekt 'Bildungsmodule zur Rolle der Biodiversität bei Anpassungen des Weinbaus an den Klimawandel' (BIODIVina) - Überblick über die Bildungsmaterialien. *Freib. Ecol. Online* **2021**, 33–56.
15. Ochoa-Hueso, R. *et al.* Nature-based strategies to regenerate the functioning and biodiversity of vineyards. *J. Sustain. Agric. Environ.* **3**, e12088 (2024).
16. Sternad Lemut, M. Canopy microclimate manipulation in the sustainable management of Pinot Noir vineyard from Vipava Valley: dissertation. ([M. Sternad Lemut], Nova Gorica, 2014).
17. Sternad Lemut, M., Sivilotti, P., Butinar, L., Laganis, J. & Vrhovsek, U. Pre-flowering leaf removal alters grape microbial population and offers good potential for a more sustainable and cost-effective management of a Pinot Noir vineyard. *Aust. J. Grape Wine Res.* **21**, 439–450 (2015).
18. *Weinbau im Klimawandel: Anpassungs- und Mitigationsmöglichkeiten am Beispiel der Modellregion Traisental (WEINKLIM)*. (2010).
19. Fichtl, L. *et al.* Towards grapevine root architectural models to adapt viticulture to drought. *Front. Plant Sci.* **14**, (2023).
20. Neethling, E. *et al. Adapting Viticulture to Climate Change- Guidance Manual to Support Winegrowers' Decision-Making*. http://www.adviclim.eu/ (2016).

21. LACCAVE: a ten-year research partnership to adapt viticulture to climate change | INRAE. https://www.inrae.fr/en/news/laccave-ten-year-research-partnership-adapt-viticulture-climate-change.
22. *Guide transfrontalier pour la conservation et la réhabilitation des paysages viticoles alpins / Guida transfrontaliera per la conservazione e il recupero dei paesaggi viticoli alpini*. (Politecnico di Torino, 2020).
23. *Neue Rebsorten im Minimalschnitt im Spalier: Die wichtigsten Fakten aus Forschung und Praxis*. https://www.zukunft-weinbau.de/wp-content/uploads/2020/11/01-Webdatei-Leitfaden.pdf (2020).
24. Böhm, L. *et al.* Crossing Old Concepts: The Ecological Advantages of New Vineyard Types. *Diversity* **16**, 44 (2024).
25. Modic, Š. *et al.* ALI LAHKO VRSTNO PESTRI POSEVKI POZITIVNO VPLIVAJO NA KORISTNE ORGANIZME V VINOGRADIH? (2022).
26. Dittrich, F. *et al.* Crop Diversification in Viticulture with Aromatic Plants: Effects of Intercropping on Grapevine Productivity in a Steep-Slope Vineyard in the Mosel Area, Germany. *Agriculture* **11**, 95 (2021).
27. Martin, C. *Espaces en terrasses et prévention de risques naturels en Cévennes*. (UMR 6012 ESPACE, Montpellier, 2006).
28. *Recupero dei terrazzamenti viticoli a Pergola Valdostana alta di Torille, Verrès*. vol. 2024 (Institut Agricole Régional).
29. Biddoccu, M. *et al.* Assessment of Long-Term Soil Erosion in a Mountain Vineyard, Aosta Valley (NW Italy). *Land Degrad. Dev.* **29**, 617–629 (2018).

30. Murets de pierre sèche | PnrBV. *Parc naturel régional des Ballons des Vosges* https://www.parc-ballons-vosges.fr/decouvrir/patrimoine-et-visites/patrimoine-naturel/murets-de-pierre-seche/.
31. Škvarc, A. & Kodrič, I. Narava in regulacija: urejanje vinogradov in sadovnjakov na terasah. *Urbani Izziv* **17**, 78–84 (2006).
32. Pepe, G. *et al.* Application of Bioengineering Techniques as Geo-Hydrological Risk Mitigation Measures in a Highly Valuable Cultural Landscape: Experiences from the Cinque Terre National Park (Italy). *Sustainability* **12**, 8653 (2020).
33. Descazeaud, M., Faraggi, T. & Soulage, J. *Murs de Soutenment: Comparaison environnementale et financière de différentes technologies*. (2014).
34. Hörl, J., Schoof, N., Luick, R. & Müller, S. *Win-Win im Weinberg (W³): Innovatives, ökologisches und ökonomisches Weinbergmanagement mit Schafbeweidung*. https://www.hs-rottenburg.net/fileadmin/user_upload/Forschung/Forschungsprojekte/Management/Win-Win/Abschlussbericht-Win-Win.pdf (2023).
35. Leyer, I., Wersebeckmann, V. & Stoll, M. *BioQuiS: Förderung der Biodiversität durch Querterrassierung im Steillagenweinbau*. (2018).
36. Bruns, A. No more Riesling?: Anpassung an den Klimawandel im Mosel-Weinbau. (2021) doi:10.25353/UBTR-XXXX-4A51-2203.
37. Nature-based solutions to increase sustainability and resilience of vineyard-dominated landscapes - ScienceDirect. https://www.sciencedirect.com/science/article/pii/S1439179124000963?via%3Dihub.

38. *Acquavitis – Inovativne rešitve za učinkovito rabo vode v čezmejnem vinogradništvu / Acquavitis – Irrigazione di precisione per una viticoltura di qualità*. (2022).
39. Crop Diversification in Viticulture with Aromatic Plants: Effects of Intercropping on Grapevine Productivity in a Steep-Slope Vineyard in the Mosel Area, Germany. https://www.mdpi.com/2077-0472/11/2/95.
40. Lipper, L. *et al.* Climate-smart agriculture for food security. *Nat. Clim. Change* **4**, 1068–1072 (2014).
41. Mazzarino, S., Letey, M., Chenal, G. & Francesia, C. Évaluations économiques de la viticulture alpine / Valutazioni economiche della viticoltura alpina. in *Guide transfrontalier pour la conservation et la réhabilitation des paysages viticoles alpins / Guida transfrontaliera per la conservazione e il recupero dei paesaggi viticoli alpini* (eds. Bonavero, F. & Cassatella, C.) (Politecnico di Torino, 2020).
42. *Weinbau mit biologisischer Vielfalt- Darstellung der Ökosystemleistungen im Weinberg*. www.life-vinecos.eu.
43. *LIFE VineAdapt- Maßnahmen für einen klimaangessten und biodiversitäts- freundlichen Weinbau*.
45. VINEAS | home. https://www.vineas.net/en/1/home.html.
46. Mazzarino, S. Outils pour la conservation et la réhabilitation des paysages viticoles alpins / Strumenti per la conservazione e il recupero dei paesaggi viticoli alpini. in *Guide transfrontalier pour la conservation et la réhabilitation des paysages viticoles alpins / Guida transfrontaliera per la conservazione e il recupero dei paesaggi viticoli alpini* (eds. Bonavero, F. & Cassatella, C.) (Politecnico di Torino, 2020).

47. Cassatella, C., Bonavero, F. & Seardo, B. M. Outils pour l'aménagement du territoire des paysages viticoles / Strumenti per il governo del territorio dei paesaggi viticoli. in *Guide transfrontalier pour la conservation et la réhabilitation des paysages viticoles alpins / Guida transfrontaliera per la conservazione e il recupero dei paesaggi viticoli alpini* (eds. Bonavero, F. & Cassatella, C.) (Politecnico di Torino, 2020).

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Annexes: Factsheets of Ecosystem-based Adaptation strategies

COVER CROPS / INTER-ROW GREENING / GREEN MANURING
Description of the EbA strategy: Cover crops are plants that are intentionally grown between rows of vines in vineyards. They are meant to improve vineyard management by enhacing soil properties, thereby reducing the need for human intervention. It could also be an alternative to herbicide. However, there is more need for maintenance than in conventional viticulture. Management involves various application methods, such as planting in all or alternating rows. Furthermore, the appropriate plants must be seeded. There is wide selection of possible plants, which can be planted in specific season, like for example in winter season. Common species include annuals like barley and oats, legumes like vetch and clover, and brassicas like daikon radish. Deciding on which species to seed or when to terminate depends also on season and wanted effect. For example, sowing in autumn is meant to provide a green manure to a vineyard over the winter period, while mowing cover crops in summer creates a mulch layer, which provides a mulch that helps reducing water evaporation from soil during hot periods in summer. The cover crops are eventually terminated through several techniques, including mechanical methods (mowing, tillage, or roller-crimping to create mulch), chemical herbicides, or through herbivory, such as allowing sheep to graze in the vineyard.
Key Ecosystem services: • Protects site from erosion • Improvement of soil structure • Improvement of soil organic matter content • Improved soil's water holding capacity • Improvement of nutrient cycling and fertility • Improvement of above and below ground fertility • Habitat for beneficial insects • Vigor control of vines • Disease reduction (lower need for spraying), lower environmental impact • Carbon sequestration

Challenges that could arise:

- Resource competition: The most significant issue is the competition between cover crops and grapevines for essential resources like water and nutrients during the growth season. This could lead to decreased vine yield.
- Pest and pathogen risks: There is a concern that cover crops could harbor or attract pests and pathogens that are harmful to grapevines, although some studies report the opposite effect.
- Economic and management hurdles: Implementing a cover crop system can involve additional costs for seeds, equipment, and management. Furthermore, managing these crops can be challenging, especially on steep slopes where specialized equipment might be required.
- Context-specific nature: The success of cover cropping is highly dependent on site-specific factors, including climate, soil type, and water availability. A strategy that works well in one vineyard may not be suitable for another, requiring careful planning and tailored management.
- Nitrogen Dynamics: While legumes can fix nitrogen, their inclusion in cover crop mixes, particularly without reducing other fertilizer inputs, can lead to increased N2O emissions. The application of wood chips (BRF) can also lead to temporary nitrogen-blocking issues, especially in the first year.

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FALLOW LAND GREENING
Description of the EbA strategy: Fallow land greening involves cultivating diverse plant communities on non-cropped areas, such as unused plots or strips of land located within or next to vineyards. The goal is to establish species-rich vegetation that can be either intentionally sown with regional seeds or allowed to develop naturally over time. These greened areas require regular maintenance, typically mowing once or twice a year, to prevent overgrowth by shrubs and trees and to maintain a flower-rich, grassland-like state that provides maximum ecological benefits.
Key Ecosystem services: • Biodiversity promotion • Improvement of soil health and protection • Improvement of water absorption • Reduction of soil erosion • Enhancement of organic matter content • Enhancement of nutrient supply • Carbon sequestration • Pest and weed management • Carbon sequestration • Reduction of emisions of greenhouse gasses from the soil


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MULCHING / SOIL COVER WITH ORGANIC MATERIAL
Description of the EbA strategy: Mulching is a vineyard management practice where the soil surface, particularly beneath the vines, is covered with a layer of organic material. The primary function of this cover is to block sunlight from reaching the ground, which effectively inhibits the growth of weeds and allows the vine's root system to thrive without competition. A variety of organic materials are used for this purpose, including hay, straw, compost, leaves, bark, and shredded residues from the vineyard itself, such as vine pruning cuttings and wood chips.
Key Ecosystem services: • Weed control • Improvement of water-holding capacity of soil • Improvement of soil health and fertility • Temperature control of soil surface • Reduction of soil erosion • Improved vine growth (food production)

Challenges that could arise:

- Pest Issues: The mulch layer can create an ideal shelter for pests such as rodents, snails, and earwigs, potentially leading to an increase in their populations.
- Operational and Economic Costs: The application of mulch can be more expensive and labour-intensive than conventional chemical weeding. It can also create practical difficulties during harvest.
- Material-Specific Risks: Certain materials carry unique risks. For example, bark mulch can contain contaminants like Cadmium, wood chips can temporarily lock up nitrogen in the soil during their first year of decomposition, and nutrient-rich materials like spent mushroom compost can inadvertently fertilize and encourage weed growth.
- Risk of Excessive Growth: The improved soil fertility and moisture can sometimes lead to excessive vegetative growth in the vines, which may increase the risk of fungal diseases if not properly managed.

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NO TILLAGE / REDUCED TILLAGE
Description of the EbA strategy: Practices such as limiting soil perturbation through reduced or no soil-tillage, along with conserving diversified and permanent vegetation cover in interrows, are considered key nature-based solutions with significant beneficial effects[3]. Regenerative viticulture, for instance, actively promotes no-tillage, organic amendments, and cover cropping[5].
Key Ecosystem services: • Improved soil structure and aggregation • Increased organic matter • Enhanced nutrient cycling and availability • Increased water infiltration and retention • Reduced runoff and erosion • Water quality protection • Maintain soil moisture • Carbon sequestration and GHG reduction • Enhanced resilience to climate extremes • Increased above- and below-ground biodiversity • Pollination services • Biological pest and disease control (lower environmental impact) • Landscape aesthetics and recreational value

Challenges that could arise:

- Water competition: Cover crops and other vegetation can compete with grapevines for water and nutrients, especially in dry regions, during arid years, or on dry sites. This competition can lead to water stress for the vines, particularly on very dry locations and in low-rainfall years, necessitating careful water management, such as reduced or alternating greening in rows and regular rolling or mulching to minimize water consumption.
- Yield reduction: Some studies indicate that certain no-till or min-till cover crop treatments can result in significant yield reductions. Pre-flowering leaf removal can also cause substantial yield reduction. Intense water stress can also lead to a considerable reduction in grape production.
- Pest and Disease Management: No-tillage or reduced tillage while beneficial for soil, can sometimes create shelters for pests like earwigs, rodents, and snails. Some cover crop species can potentially provide habitats for pests and pathogens. Unmanaged wild rootstocks in abandoned vineyard areas can also pose a phytosanitary problem, serving as sources for pests and diseases.
- Soil Degradation Risks: While generally protective, unadopted grazing management can lead to a reduction in species frequency and diversity, and even degrade entire ecosystems. Inappropriate grazing can also lead to the formation of vegetation-free paths on slopes, potentially increasing erosion. Mechanical under-vine cultivation in steep slopes is highly problematic due to increased erosion and loss of soil fertility, considered environmentally questionable.

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HUMUS / ORGANIC MATTER INCREASE
Description of the EbA strategy: Soil organic matter (SOM) comprises the totality of dead organic substances in the soil, with humus being a significant, stable component of this. Although SOM constitutes only a small percentage of the soil's mass, it profoundly influences all soil functions. A large portion of the world's carbon reserves, over 75% or 775 Gt, is stored in the soil as roots and organic substances, accumulating as difficult-to-decompose humus over long periods. Practices like green manure contribute to humus and organic matter. While some carbon is lost as CO_2 during the decomposition of green mass, plants with higher lignin content, such as grasses, degrade slower and form more stable organic matter. Conversely, legumes, with a lower carbon-to-nitrogen (C/N) ratio, lead to more labile organic matter and more intense mineralization. Other methods include mulching with organic materials like hay, straw, leaves, and bark, and the use of compost and shredded woody material (BRF - Bois Raméal Fragmenté), which reintroduces high-quality lignin to form stable humus. Promoting soil quality through good root penetration also fosters humus accumulation.
Key Ecosystem services: • Improved soil structure and aggregation • Enhanced nutrient cycling and availability • Increased water infiltration and retention • Erosion control • Support for soil biodiversity • Carbon sequestration • Enhanced resilience

Challenges that could arise:

- Limited contribution from certain practices: green manure, while beneficial, may only contribute a relatively low amount to stable humus annually, as a portion of the organic matter mineralizes quickly and is not stable long-term. This necessitates additional organic sources, which might not always be readily available or of consistently good quality in the market.
- Competition for resources: Cover crops, used to build organic matter, can compete with the primary crop (e.g., grapevines) for water and nutrients, especially in dry environments or during arid periods. This competition can lead to water stress for the main crop and potentially reduced yields.
- Cost and labour: Implementing strategies to increase organic matter, such as mulching or applying organic amendments, can be more time and cost-intensive than conventional practices like chemical weeding.
- Nitrogen dynamics: The decomposition of organic matter, particularly from legumes with a lower C/N ratio, leads to more intense mineralization, which can influence soil pH and nutrient availability. The use of certain organic amendments, like wood chips (BRF), can cause temporary nitrogen-blocking problems, especially in the first year after application.
- Pest and disease habitat: Mulching layers, while beneficial for soil, can occasionally provide shelter for undesirable pests such as earwigs, rodents, or snails. Some cover crop species might also inadvertently host pests or pathogens.
- Monitoring and management gaps: There is a recognized need for more comprehensive studies and better monitoring of ecosystem functions and services related to soil organic matter, especially at landscape scales. Quantitative assessments of socio-economic consequences for farmers are also often lacking. Farmers may not consistently prioritize humus supply if management responsibilities change annually.
- Climate-induced microbial activity: While soil stores carbon, rising temperatures can accelerate pedogenesis and increase microbial respiration, converting both fresh and old organic matter into CO2 and releasing it into the atmosphere. This process could potentially turn soils, even forests, into a carbon source if the release exceeds sequestration.
- Heavy metal accumulation: In some agricultural areas, particularly vineyards, there can be an elevated accumulation of substances like copper, which approaches phytotoxicity limits. While maintaining high organic matter levels can help minimize associated risks, it also highlights a potential challenge if the organic matter itself introduces contaminants or if its protective capacity is overwhelmed.


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SOIL AMENDMENTS / BIOCHAR / COMPOST
Description of the EbA strategy: Organic soil amendments are aimed at improving soil nutrient status, water management, soil organic matter, and carbon content. They represent a transformation in how crops receive nutrients, moving away from dependence on synthetic chemical fertilizers that can reduce microbial biomass, species diversity, and contaminate groundwaters. A meta-analysis indicated that organic amendments can increase soil organic carbon stock by 44%. When combined with no-tillage systems, this can lead to a significant soil organic carbon sequestration rate of 11.06 Mg CO_2-eq. per hectare per year. Common types of organic soil amendments include: • Bio stimulants • Biochar, • Composts (e.g., vermicompost, mushroom compost, farmyard manure), • Cuttings from vine pruning, • Winery waste products, • Wood chips. Repeated applications of these amendments, such as composts and manures at rates of approximately 4 t ha-1 year-1 fresh weight over several years, have been shown to significantly increase soil nutrients (nitrogen, phosphorus, potassium), SOM content, and microbial biomass. They also contribute to enhanced aggregate stability and soil structure, which improves water infiltration and water holding capacity.
Key Ecosystem services: • Increased soil health and fertility • Water management • Nutrient provision • Waste valorisation • Disease management

Challenges that could arise:

- Nutrient imbalance: Elevated concentrations of plant-available nitrogen from amendments can lead to excessive vigour in vines, increased malic acid, and lower anthocyanin content, negatively affecting red wine quality. Similarly, increased potassium content in grapes and musts due to compost can be undesirable, potentially leading to high pH, lower tartrate: malate ratio, and reduced wine stability. These issues can sometimes be mitigated by using carbon-rich amendments like straw or composted vine cuttings.
- GHG emissions: Studies have reported temporary increases in CO_2 and N_2O emissions following organic amendment applications, with daily N_2O emissions potentially rising by as much as 400% for a couple of weeks after application. However, other studies have found no significant differences in cumulative soil GHG emissions or soil carbon stocks with varying compost rates, possibly due to short study durations, broad application across the vineyard floor, or already sufficient soil nitrogen.
- Risk of pests/pathogens: Using uncomposed vine pruning cuttings and winery waste products may carry a risk of harbouring vine pests or pathogens.
- Monitoring needs: Careful monitoring of the vineyard's nutrient status (soil and vine petioles) is crucial after compost applications to address any deficiencies or excessive concentrations and to monitor wine chemistry and non-target impacts like nutrient leaching. The effects of composts are dependent on climate, soil type, and other soil properties, leading to varying responses across vineyards.
- Knowledge gaps: Long-term research is recommended to better understand the impact of organic soil amendments on soil nutrient dynamics, GHG emissions, and grape chemical composition, considering interactions between soil type, rootstock, scion genotype, climatic conditions, and application timings/rates.
- Wood chips (BRF - Bois Raméal Fragmenté): BRF is a practice that reintroduces high-quality lignin into the soil from shredded wood residues of broad-leaved trees to form stable humus. While it improves soil structure, nitrogen, phosphorus, and water management, it can cause temporary nitrogen-blocking problems in the first year. It's recommended to apply BRF in autumn-winter to Favor fungal settlement.
- Superabsorbent polymers (SAPs) / Hydrogels (as soil conditioners): Superabsorbent polymers (SAPs), particularly starch-based hydrogels, are being explored as soil conditioners due to their high-water absorption capacity. These hydrogels can absorb water from moist soil, and their swelling increases porosity, leading to improved soil ventilation. Studies have shown specific IPN (interpenetrating network) hydrogels, such as PVP/PAAm (Polyvinylpyrrolidone/Polyacrylamide), to significantly influence plant growth in soils with heavy metals and high pH. However,

starch itself in agriculture might promote microbial growth that could compete with plant roots for nutrients, potentially stunting plant growth.

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PRECISION FERTILIZATION
Description of the EbA strategy: Precision fertiliser amount refers to the careful adjustment of nutrient application to match the specific nutritional demands and growing conditions of plants, such as grapevines. In vineyards, this practice is crucial for maintaining proper growth and fruitfulness, involving both macro- and micronutrient supplementation. The decision to apply fertilisers should be based on visual observations of vine growth and interpretations of vine tissue analyses. In sustainable viticulture, including integrated, organic, and biodynamic approaches, the goal is to limit the type, quantity, and timing of both pesticide and fertiliser application. This needs-based approach is often legally mandated and regulated, for instance, by the German Fertilizer Act and Fertilizer Ordinance (DüV), which requires soil analysis to determine plant-available nutrient quantities. For operations exceeding 2 hectares, nitrogen fertiliser needs (over 50 kg N/ha/year) must be determined and documented, with soil examinations typically performed every 3-5 years, or at least every 6 years. A delicate balance of bioavailable nutrients is essential for producing high-quality grapes and wines. Managing humus content and applying organic fertilisers, such as grape pomace, also falls under needs-based fertilization, with humus content checks recommended every 6-10 years.
Key Ecosystem services: • Increased soil health and fertility • Nutrient cycling and availability • Carbon sequestration • Water management • Increased yield quality and quantity • Reduced environmental degradation • Biodiversity support
Challenges that could arise: • Greenhouse Gas Emissions: Fertilisation, especially through fertigation, can contribute to an increase in greenhouse gas emissions. • Operational constraints: Implementing precise fertilisation requires regular soil and plant tissue analyses, which might incur costs and demand specific expertise. Timely access to necessary inputs (e.g., specific fertilisers or even bio stimulants) can also be a constraint for widespread adoption.


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GRAZING BY ANIMALS
Description of the EbA strategy: Grazing by animals involves the integration of livestock into crop production systems, a practice often referred to as integrated crop-livestock systems or agro-silvopastoral systems[5,9,10]. This traditional approach has been applied in vineyards to enhance functional biodiversity and can serve as a nature-based solution for sustainable land management. Sheep are the most commonly integrated animals in vineyards, supporting or partially replacing labour- and fuel-intensive tasks typically performed mechanically, chemically, or manually. Geese have also been utilized in vineyards to graze grass, while hens have been found beneficial in olive groves for pest control and soil aeration. Grazing periods can vary, including winter grazing during the vine's dormancy, or summer grazing during the growing season. Winter grazing is generally considered less risky in common Central European vine training systems. In some instances, continuous year-round grazing might be achievable with specific vine training systems and protection during sensitive development phases of the plants. Historically, grazing animals enabled the use of lands difficult to cultivate, contributing to diverse landscapes. However, modern intensive grazing, focused on maximizing animal production, contrasts with extensive, nature-oriented grazing aiming for biodiversity conservation.
Key Ecosystem services: • Weed and vegetation control • Increased soil health and fertility • Nutrient cycling and organic inputs • Carbon sequestration • Improved soil structure and water retention • Reduced soil perturbation • Erosion control • Biodiversity promotion • Pest control • Economic benefits • Social and cultural values

Challenges that could arise:

- Damage to crops: Animals, especially sheep, can cause damage to vines by stripping cordons, browsing leaves, or damaging young grapes, particularly during the growing season. This risk is heightened with unadapted vine training systems in regions like Central Europe.
- Soil compaction: Inappropriate grazing intensity or management, including the breed, size, and number of livestock, as well as the timing and duration of grazing, can lead to soil compaction.
- Water competition: Grazing vegetation may compete with vines for water resources, especially in arid or Mediterranean regions, potentially causing water stress in the main crop. This necessitates careful monitoring and management of soil moisture.
- Increased workload and costs: Implementing grazing often involves additional expenses for animal handling, fencing, continuous monitoring, watering infrastructure, and shelter. Summer grazing, in particular, may demand significant operational adjustments and higher labour costs.
- Breed selection and suitability: Identifying suitable animal breeds is crucial, as desirable traits like robustness, low mouth height, and inability to stand on two legs are not universally present in all breeds. Larger, heavier breeds can pose greater challenges.
- Interaction with pesticides: The use of fungicides like copper in biological viticulture can be problematic for grazing animals, as sheep, for example, are extremely sensitive to copper, necessitating careful consideration of veterinary concerns and limiting the use of such substances.
- Negative impacts on biodiversity: If grazing is not managed appropriately (e.g., high stocking density or prolonged grazing periods), it can lead to a loss of less grazing-tolerant plant species, localized nutrient accumulation (eutrophication), and soil erosion on slopes. Intensive grazing does not inherently correlate with increased biodiversity.
- Operational complexity: Integrating animal grazing requires meticulous coordination between viticultural practices and animal husbandry needs, including grazing timing and protecting sensitive vine development phases.
- Economic viability concerns: While grazing offers economic benefits, these are contingent on effective management and, ideally, the utilization of animal products. Without generating income from animal products, the savings from reduced machinery and labour might be offset by other costs, such as travel for animal care, which could even increase the carbon footprint.
- Knowledge gaps: There is a recognized need for more holistic research to assess the synergies and trade-offs between different vineyard management practices and ecosystem services, especially when combining various nature-based strategies like grazing. Detailed

	descriptions of vine training systems are essential for meaningful research outcomes.
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VEGETATED BUFFER STRIPS / FLOWER STRIPS
Description of the EbA strategy: Vegetated buffer strips and flower strips involve the establishment of diverse plant communities within or adjacent to agricultural fields, such as vineyards, to enhance ecological functions and promote sustainability. These practices are often referred to as ground vegetation management by cover cropping, conservation of native ground cover, or the use of green manure. These vegetated areas can take various forms: • Flower strips are established to act as valuable biotope islands, particularly in hard-to-manage, short or pointed rows within vineyards. • Cover crops involve sowing regional seed mixtures or allowing spontaneous vegetation between vine rows, with the goal of achieving permanent ground cover. These can consist of diverse plants, including legumes or grasses, or complex communities of native species from different functional groups. • Green manure specifically refers to growing annual plants between rows, typically planted after harvest and then mowed, shredded, and incorporated into the soil in the pre- or post-flowering phase. Common seed mixes include Legumes, Gramineous (Poaceae), and Brassicaceae (Cruciferous) families, with additions like Phacelia for honeybees. • Terrace embankments in modern steep-slope viticulture also offer significant non-cropped areas that can be revegetated to establish species-rich plant communities, contributing to biodiversity refugia and habitat networking. Hydro-seeding with regional seeds is a recommended method for such revegetation. • Edges and corners are unmanaged or extensively managed peripheral areas along paths or at the boundaries of vine plots, where typical herbaceous plants of dry grasslands thrive. These areas serve as connecting elements between open and vegetated biotopes.
Key Ecosystem services: • Biodiversity enhancement • Habitat and food source • Increased species richness • Create ecological networks • Cultural landscape preservation • Improvement of soil health and functioning • Erosion control • Water management • Improved nutrient cycling and organic matter • Improved soil structure • Disease reduction (lower need for spraying), lower environmental impact • Carbon sequestration • Reduced emissions


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RESTORATION OF RUNOFF CHANNELS / GUTTERS
Description of the EbA strategy: Restoration of runoff channels and gutters involves transforming artificial or degraded water conduits back into more nature-orientated, ecologically functional elements within a landscape, such as vineyard-dominated areas. This practice is a type of nature-based solution aimed at leveraging ecosystem functions to address societal challenges. Specific forms and components of this practice include: • Diversion ditches: These are soil structures built across slopes to collect water and channel it into natural drainage ways. They are typically seeded and gently graded to slow down water flow, thereby reducing its erosive force. These can significantly reduce the amount of water flowing through an area, potentially by as much as 80% in a vineyard. • Water and sediment control basins: These structures are created by raising a berm across a gully and incorporating a subsurface outlet pipe at the base of the slope. Their purpose is to collect runoff, slow down the water, and trap sediment, effectively stopping erosion. • Watercourse restauration: This involves the revitalisation of existing watercourses, including improving their structural quality. This can mean widening stream channels, removing artificial bank reinforcements, creating structures with deadwood, and renaturing artificial ditches. It emphasizes the goal of water retention across the area, aiming for a temporary prolongation of runoff time and increased infiltration through elements like small floodplains. • Restoring natural retention areas: This includes re-establishing natural floodplains along watercourses to provide protection against floods. • Maintaining vegetated low areas: Designing vineyards with row breaks around natural depressions (swales) and maintaining these low areas in sod can help filter runoff and reduce erosion.
Key Ecosystem services: • Erosion control and sediment management • Water management and flood/drought mitigation • Water quality improvement • Biodiversity enhancement • Improved soil health and fertility

Challenges that could arise:

- Knowledge gaps and assessment complexity: There is a general lack of holistic research explicitly measuring multiple ecosystem functions and services at a landscape scale in vineyard systems. This includes understanding the potential consequences of these practices on microbial communities, pest/pathogen damage, biomass production, and farmers' income. It can be difficult to rigorously evaluate the effectiveness of these interventions due to challenges in establishing causality and the long-term nature of adaptation outcomes.
- Implementation and management complexity: Designing and implementing these solutions requires a multidisciplinary understanding of the relationships between environmental changes, biodiversity, and socio-ecosystem functioning. Tailoring solutions to local conditions is essential, as not all options are equally effective under all circumstances. The effort and scope of implementation can vary significantly.
- Economic feasibility: While nature-based solutions can be cost-effective in the long term, the initial investment costs can be a barrier for farmers. There's a need for better quantitative assessments of the socio-economic consequences for farmers and other stakeholders.
- Competition for water resources: Climate change is projected to lead to less water availability and increased demand, intensifying existing and creating new conflicts over water use, particularly in summer months and at lower altitudes. This could complicate the allocation of water for renaturation efforts and maintaining ecological flows.
- Regulatory alignment: Current planning measures in some regions, particularly concerning water management, do not explicitly consider climate change impacts and adaptation possibilities, which may hinder the integration and effectiveness of these nature-based solutions.
- Unintended consequences: While generally beneficial, specific designs or local conditions might lead to unexpected issues. For instance, poorly designed structures could potentially concentrate issues rather than solve them, though this is not directly stated for runoff channels in the sources provided, it is a general concern for ecological interventions.

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RESTORATION OF WATERWAYS / VERGES
Description of the EbA strategy: The restoration of waterways and verges involves transforming degraded or artificial water bodies and their surrounding strips of land (verges) back into more nature-oriented and ecologically functional states. Specific forms and components of this practice include: Watercourse restoration: This involves the revitalization and structural improvement of existing watercourses. Methods can include widening stream channels, remove artificial bank reinforcements, and create structures with deadwood. It also encompasses the restoration of artificial ditches. The overarching goal is to promote water retention across the area, leading to a temporary prolongation of runoff time and increased infiltration, for example, by creating small floodplains. • Re-qualification of rivers: This includes considering the "minimal vital flow" and ecological status of rivers. • Creation of buffer zones: Establishing vegetated buffer zones between rivers and cultivated areas helps protect the ecological integrity of riparian and lateral transition zones. • Restoring natural retention areas: This involves re-establishing natural floodplains along watercourses to provide protection against floods.
Key Ecosystem services: • Water management • Flood/drought mitigation • Biodiversity enhancement • Improved soil health • Erosion control • Cultural and aesthetic value

Challenges that could arise:

- Implementation and management complexity: Requires a multidisciplinary understanding of the complex relationships between environmental changes, biodiversity, and socio-ecosystem functioning. Thus, tailoring solutions to local conditions is crucial, as not all options are equally effective everywhere.
- Economic feasibility: The initial investment costs for restoration can be a significant barrier for farmers and communities. There is a risk of unprofitability and increased operational costs associated with these practices.
- Water resource competition: Climate change projections indicate decreased water availability during summer for agricultural and human consumption, intensifying conflicts over water use. Drought events are expected to become more frequent and severe, posing challenges for maintaining restored water features. Competition for water between cultivated crops (e.g., vines) and vegetation in verges can lead to water stress in the main crop, particularly in arid regions.
- Potential negative impacts and conflicts: Poorly designed interventions could potentially introduce foreign materials or pollutants into ecosystems. While generally beneficial, certain practices might also create undesired disservices, such as providing habitats for pests and pathogens if not managed appropriately. Without proper management, there is a risk of the monotonization of the landscape and reduction of biodiversity.


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DRIP IRRIGATION / RESOURCE-SAVING IRRIGATION
Description of the EbA strategy: Drip irrigation, or resource-saving irrigation, is a precise water management technique primarily implemented in agricultural settings, such as vineyards, to conserve water and optimize its use. The core principle is to avoid water waste by supplying water directly to the plant's roots in measured quantities, allowing for targeted and efficient water use. Key aspects of this practice include: • Precision and targeted delivery: Drip irrigation systems allow for precise control over the amount of water each plant receives, down to the drop. This contrasts with traditional irrigation systems where water might be applied less discriminately. • Monitoring and control: An agroecological approach to resource-saving irrigation involves monitoring soil humidity and available water for vines in real-time. This can be achieved by placing simple, low-cost humidity probes and data loggers in the vineyard soil. This data, combined with soil-water balance models based on meteorological information, enables farmers to irrigate at the optimal time and with the appropriate quantity of water. • Deficit irrigation strategies: This approach involves applying only a portion of the water lost through crop evapotranspiration during the growing season or specific phenological phases. The goal is to maintain plants under conditions of controlled stress, which can positively influence grape quality while significantly reducing water consumption. Specific deficit levels can be set, for example, by aiming for pre-dawn water potential ($\Psi_{predawn}$) values of -0.35 MPa for moderate stress or -0.55 MPa for severe stress, as opposed to -0.2 MPa for well-irrigated control conditions. Decision Support Systems (DSS) can be used to differentiate irrigation strategies and define desired water potential thresholds across vegetative stages. • Fertigation: Drip irrigation systems also allow for efficient application of fertilizers along with water, known as fertigation.
Key Ecosystem services: • Water conservation and efficiency • Enhanced crop productivity and quality • Soil health improvement • Reduced environmental impact

Challenges that could arise:

- High initial investment costs: Drip irrigation systems can be expensive to install. This can be a significant barrier for farmers, especially those with small holdings.
- Water scarcity and competition: While designed to save water, these systems are used in contexts where water availability is decreasing and demand is increasing, particularly during summer for agricultural and human consumption. This can intensify conflicts over water resources among various sectors (civil use, tourism, industry). Drought events are expected to become more frequent and severe, putting further pressure on water resources.
- Soil salinization: In arid regions, if winter rainfall is insufficient for leaching, irrigation can lead to a build-up of salt in vineyard soils. Vines are highly sensitive to salt, and its accumulation can render soils unsuitable for grape production.
- Impact on grape and wine quality/style: Over-irrigation can negatively affect grape quality. Conversely, excessive water deficit can lead to incomplete and unbalanced ripening of grapes, particularly affecting polyphenols and aromatic compounds. There are also concerns about potential changes in the characteristic "wine style" or taste due to irrigation. Different grape varieties respond differently to stress, meaning a universal deficit irrigation plan may not be suitable.
- Technological and management complexity: Implementing precise irrigation requires accurate monitoring of soil moisture and plant water status, which can be complex. Maintaining a predefined level of plant water potential (e.g., $\Psi_{predawn}$) is challenging because plants adapt to imposed conditions, and models calibrated for arid environments might fail in rainier climates. The fragmentation of land ownership can make it difficult for individual farmers to manage irrigation, often requiring coordination through consortia.
- Increased energy and greenhouse gas emissions: While not directly stated for drip irrigation specifically, increasing water use for irrigation generally implies additional energy consumption for pumping and distribution, potentially leading to increased greenhouse gas emissions.
- Nitrogen leaching: There is a risk of increased nitrogen washout (nitrate pollution of groundwater) if not managed correctly, especially when fertilization is combined with irrigation.
- Lack of integrated planning: Current water management planning measures may not explicitly consider future climate change impacts and adaptation possibilities, hindering the full integration of resource-saving irrigation strategies. There is a need for better coordination across policy domains and between agricultural and climate change strategies


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DRAINAGE SYSTEMS
Description of the EbA strategy: In the context of the provided sources, "drainage systems" are generally described not as a single, engineered infrastructure but as a combination of practices and structures designed to manage water flow, prevent waterlogging, and control erosion within landscapes, particularly in agricultural settings like vineyards. These systems aim to mitigate the impacts of both excessive water and water scarcity by regulating the hydrological cycle. Key components and practices associated with drainage and water management include: • Diversion ditches are soil structures built across slopes to collect and redirect surface runoff into natural drainage ways, slowing the water's flow and reducing its erosive force. These can significantly reduce runoff from vineyards. • Water and sediment control basins involve raising berms across gullies, often with subsurface outlet pipes, to collect runoff and sediment and halt erosion. • Drainage tiles are subsurface systems, commonly used in soils with moderate to heavy textures. They reduce surface runoff when soils are saturated and allow water to be filtered through the soil, removing contaminants. • Water retention structures are depressions or ditch pockets designed to temporarily hold surface runoff, allowing it to infiltrate the soil rather than flowing off rapidly. These measures contribute to decentralized flood protection. • Watercourse renaturation involves revitalizing and reconstructing watercourses, potentially by widening them, removing artificial bank reinforcements, and creating natural structures like deadwood. The objective is to retain water in the area, delay runoff, and increase infiltration, for instance, by creating small flood depressions. • Dry stone-walls are traditional masonry constructions built without or with minimal binding agents. They are crucial for maintaining hillside and mountain land arrangements and naturally facilitate the drainage of rainwater. A backing of crushed stones can further aid in draining excess water and reducing hydrostatic pressure on embankments. These walls are functional elements within the viticultural landscape, contributing to water evacuation. • Vineyard layout, such as planting rows across slopes instead of up and down, can reduce erosion by up to 50%. • Cover crops and greened embankments provide a permanent vegetation cover that helps prevent soil loss, maintains stability, and enhances the soil's water absorption capacity.

Key Ecosystem services: • Erosion control and soil stabilization • Water regulation and flood protection • Water quality improvement • Soil health and fertility enhancement • Biodiversity support
Challenges that could arise: • High investment and maintenance costs: The initial installation of comprehensive water management infrastructure can be expensive, posing a significant barrier, particularly for smaller agricultural holdings. Traditional structures like dry stone walls, while ecological, require ongoing labour and maintenance due to dynamic environmental conditions. • Environmental quality degradation risks: Increased nutrient and sediment transport in rivers can degrade water quality. Improper management, especially when combining fertilization with irrigation, can lead to nitrogen leaching and groundwater contamination. • Potential for unintended ecological consequences: Restoration efforts or habitat creation require careful planning to ensure they align with existing biodiversity and do not create new ecological imbalances or conflicts with other land uses. • Socio-economic factors: There is a need for better farmer incentives, a positive public image, and robust financial models to support the adoption and long-term sustainability of these practices, as current efforts may face challenges like increased workload and costs for farmers.


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MICRO WATER STORAGE / WATER RETENTION TROUGHS
Description of the EbA strategy: Micro water storage, often referred to as water retention troughs or depressions, are specific structures or natural features designed to temporarily hold surface runoff water on agricultural land, particularly within vineyards. These can manifest as fixed soil depressions or small, shallow water spots, sometimes established in the understock area of vines, especially where drip irrigation systems are present. The primary purpose of these features is to prevent rapid surface runoff and to promote the infiltration of water into the soil. In the context of livestock management within vineyards, water tanks or natural water sources can also serve as watering troughs to meet animal water requirements. These practices are integrated into broader sustainable soil and water management strategies, often complemented by elements like specialized ground cover seed mixtures or mulching techniques that also enhance water retention.
Key Ecosystem services: • Water regulation and retention • Flood and erosion control • Soil health and fertility enhancement • Biodiversity support
Challenges that could arise: • Risk of waterlogging: When creating retention depressions, it may be necessary to improve soil permeability to ensure effective infiltration and prevent undesirable waterlogging, which could negatively impact plant roots. • Investment and maintenance costs: Although often considered low-cost techniques, the initial installation of such infrastructure can still incur costs. For instance, providing watering troughs for livestock requires investment. Larger-scale water storage facilities can be substantially expensive.

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LAND REORGANISATION / CONSOLIDATION
Description of the EbA strategy: Land reorganisation, often referred to as land consolidation, is a strategic approach to managing and restructuring agricultural land and broader territories. It involves planned changes to land use patterns and property boundaries to improve efficiency, sustainability, and resilience. This process can serve as a starting point for further land development and is a key action within sustainable land management and climate change adaptation strategies. It explicitly addresses challenges such as land fragmentation, aiming to create more coherent and manageable agricultural units. Land reorganisation often integrates with broader agroecological principles, promoting participatory landscape design and sustainable management of local resources. This includes the recovery and management of uncultivated or abandoned lands, potentially through collective management forms like land associations or consortia. The ultimate goal is to evolve traditional landscapes while integrating innovative elements, ensuring a balance between productive and environmental functions.
Key Ecosystem services: • Soil health and erosion control • Landscape preservation and cultural value • Economic and social benefits
Challenges that could arise: • Landscape transformation and social acceptance: Changes to the existing landscape appearance can be a major point of contention and conflict. There can be resistance from local planners and politicians who may hesitate to implement such activities if they lead to restrictions on urban development or conflicts with other local interests. Lack of acceptance from stakeholders (e.g., for habitat creation) is also a hurdle. • Technical and operational difficulties: Overcoming land fragmentation remains a practical and technical challenge. New structures, like cross-terracing, may introduce risks such as uncertain slope stability and the potential for waterlogging if not properly assessed and managed. Furthermore, the removal of invasive forests from abandoned terraces can be difficult due to existing forest and landscape protection regulations.

BIODYNAMIC VITICULTURE
Description of the EbA strategy: Biodynamic viticulture is recognized as a form of sustainable viticulture, alongside integrated and organic farming practices. The fundamental aim of these sustainable approaches, including biodynamic, is to limit the type, quantity, and timing of pesticide and fertilizer application in vineyards. This restriction is driven by a heightened awareness and concern for human health and the environment. Sustainable agro-ecosystems, which encompass biodynamic viticulture, are characterized by their ability to maintain their resource base, minimize external artificial inputs, manage pests and diseases through internal regulating mechanisms, and recover from cultivation and harvest disturbances.
Key Ecosystem services: • Biodiversity conservation and enhancement • Soil health and fertility improvement • Pest and disease regulation • Reduction of chemical inputs
Challenges that could arise: • Impact on yield and economic margins: Studies on organic farming indicate that it may reduce wine production, potentially leading to no significant differences in overall multifunctionality or economic margins compared to non-organic systems. This suggests that a shift to such practices does not always guarantee immediate economic benefits in terms of yield. • Investment and costs: Transitioning to sustainable practices, even if considered "low-cost" in some aspects, can involve initial investments and increased operational costs. Farmers may face challenges in adapting viticulture workflows to new requirements, such as those related to managing vegetation without synthetic herbicides or pesticides. • Microbial ecology understanding: While soil microbial communities are crucial for soil health, there is still insufficient knowledge about the specific functional roles most microorganisms play in vineyards. This lack of understanding can hinder the optimization and regeneration targets for soil and plant-associated biodiversity.


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CANOPY MANAGEMENT & PRUNING MANAGEMENT
Description of the EbA strategy: Canopy management in viticulture refers to a range of techniques applied to a grapevine plant to alter the position or number of leaves, shoots, and fruit in space to achieve a desired arrangement and optimize the vine's or grape's zone microclimate. The vine's canopy consists of its above-ground parts, including shoots, leaves, fruit, trunk, and cordon. The aim is to create an optimal microclimate for grape quality, inflorescence initiation, and cane maturation. This involves influencing microclimate factors such as solar radiation, light exposure, wind speed, air temperature, and humidity. Key canopy management techniques include: • Shoot positioning: Orienting shoots to create a uniform distribution of foliage that minimizes fruit shading. This is typically done one to two weeks post-bloom. • Shoot thinning: Reducing the number of shoots. • Hedging: Trimming shoot growth. • Leaf removal (defoliation): A frequently applied summer operation, particularly in the fruit-zone, which involves eliminating some or all leaves around the shoot base. This technique improves illumination and air circulation around the grape clusters. Leaf removal can be performed at different phenological stages of grape berry development, such as pre-flowering, berry set, or veraison, with varying effects on vine physiology and grape composition. • Cluster thinning (crop thinning): A practice to adjust fruit yields, removing undersized, poorly set, or immature clusters to achieve optimum ripeness and a balance between fruit and canopy. This can be done from pre-bloom up to harvest. • Pruning management, specifically referring to practices like late spur-pruning, can also be used as a short-term strategy to delay the grapevine's development cycle, such as the onset of ripening (véraison). Another specific pruning system mentioned is the perennial cordon system, where grapes hang higher off the ground from a solid horizontal wood stem, creating a wall of leaves with grapes on top.
Key Ecosystem services: • Improved yield quality and quantity • Disease reduction (lower need for spraying), lower environmental impact • Biodiversity enhancement

Challenges that could arise:

- Impact on yield and economic margins: Yield reduction is an inherent goal of some thinning strategies, such as pre-flowering defoliation, which can lead to a substantial decrease in yield. While some practices can reduce overall costs by eliminating other operations, manual leaf removal can be labour-intensive and expensive.
- Risks to vine health and grape quality: High temperatures (>35°C) resulting from excessively open canopies can decrease shoot growth, shut down photosynthesis, reduce sugar accumulation, and lead to rapid acid degradation. Increased sun exposure due to canopy opening, particularly with later leaf removal, carries the risk of sunburn on berries and can inhibit technologically important biosynthetic processes. Intensive pruning could also negatively impact the long-term vitality of the plant. Altering canopy humidity can affect transpiration and photosynthesis, potentially reducing growth and flavonoid accumulation.
- Operational challenges: Adopting new pruning systems requires adaptation and training for workforces and careful management with machinery. Furthermore, differences in phenological stages and lateral shoot development due to timing of leaf removal can affect the total leaf area and subsequent shading.


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NEW GRAPE VARIETIES & DROUGHT-TOLERANT ROOTSTOCKS
Description of the EbA strategy: The selection and manipulation of intra-specific diversity of the cultivated plant are considered highly efficient solutions for adapting to climate change and enhancing the resilience of vineyard systems without altering crop identity or geographical distribution. Vitis vinifera, the wine grape, exhibits a vast genotypic and phenotypic diversity, encompassing an estimated 6,000 to 10,000 varieties globally, with about 1,100 commercial varieties. This high variability offers significant adaptation potential, as varieties differ in their tolerance to cold or heat, their ability to cope with drought and water stress, and their phenology. For instance, phenological stages can vary by six to ten weeks across different varieties under the same climatic conditions. New grape varieties explicitly include fungus-resistant grape varieties. These are developed to resist major diseases such as downy mildew (*Plasmopara viticola*) and powdery mildew (*Erysiphe necator*), which were historically imported to Europe and devastating to viticulture. Examples include Botrytis cinerea resistant varieties like the red-berried Iasma Eco 1 and Iasma Eco 2 (Teroldego x Lagrein crosses), and white grape varieties such as Iasma Eco 3 and Iasma Eco 4 (Moscato Cross Ottonel x Malvasia di Candia). Drought-tolerant rootstocks are plant materials chosen for their ability to thrive under conditions of water scarcity. Rootstocks play a crucial role in regulating scion vigor, water consumption, modulating phenological development, and determining resource availability through their root system architecture. They are a primary tool for vineyards to adapt to increased water deficits. Some existing rootstocks, such as 140 Ruggeri and 110 Richter, are known for their high resistance to drought. A key priority in viticultural research today is the creation of new rootstocks with even greater drought resistance.
Key Ecosystem services: • Delayed phenology • Increased drought and heat tolerance • Soil water management • Maintaining traditional cultivars • Reduced pesticide usage and disease control • Environmental protection • Increased yield quality and quantity • Environmental sustainability • Economic benefits (reduced operational costs)
Challenges that could arise: • Performance uncertainty: Growers face possible economic losses if the new variety does not reach the expected yields or fails to meet certain organoleptic (taste/quality) standards required by the market.

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ADAPTED PEST CONTROL
Description of the EbA strategy: Adapted pest control is a sustainable strategy that uses nature-based solutions to manage pests and diseases in vineyards, reducing the need for chemical pesticides. This approach focuses on creating a balanced and resilient ecosystem. The main methods include: • Enhancing biodiversity: Using diverse cover crops, flower strips, and surrounding habitats like forests and hedgerows to support natural predators (such as beneficial insects, birds, and bats) that control pest populations. • Strengthening the plant: Planting grape varieties that are naturally resistant to common diseases and using bio stimulants to improve the vine's own vigor and defense mechanisms. • Applying smart interventions: Using physical techniques like leaf removal to create a less favourable microclimate for fungi, and employing technology like pheromone traps (mating disruption) or data-driven models to guide treatment only when absolutely necessary.
Key Ecosystem services: • Environmental protection and biodiversity conservation • Improved soil health • Reduced operational costs • Optimized resource use • Enhanced human health and food safety
Challenges that could arise: • Technical and practical hurdles: Decision-support tools rely on accurate weather forecasts, which can be unreliable, and may not cover all diseases. Physical methods also have downsides, like the fire risk from flame-weeding or difficulties with mechanical weeding in wet or rocky soil. • Economic and social barriers: The high initial cost of new technologies and practices is a major barrier, especially for smaller farms. Additionally, both farmers and consumers can be resistant to abandoning traditional methods or grape varieties, especially if there isn't a clear market benefit or certification for more sustainable products. • Risk and unintended consequences: Overusing any single method, even a sustainable one, can lead to pests developing resistance. Some beneficial practices, like mulching, can also create habitats for other pests (e.g., snails, rodents), and farmers may fear that abandoning chemicals will reduce their yield or quality.

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VINEYARD RELOCATION / REORIENTATION

Description of the EbA strategy:

Vineyard relocation or reorientation refers to strategic changes in the physical location, layout, and design of vineyards to adapt to evolving environmental conditions, particularly climate change, and to enhance sustainability and resilience. This can involve choosing new growing areas, altering row orientation, or restructuring existing vineyard plots.

Climate change predictions suggest significant impacts on grape production, including increased pest pressure, reduced and variable crop yields, and a strong mismatch between regional climate and crop phenology. These challenges necessitate major shifts in growing areas. Vineyard relocation or reorientation can address these by:

- Adapting site selection and design: This involves carefully selecting new vineyard sites and designing their layout to optimize for future conditions. A comprehensive strategy requires well-selected long-term practices, including choices of site and soil type, soil mapping, establishment techniques, rootstock-scion combinations, trellising and training systems, vine spacing, and row direction. One reaction is to choose more warmth-loving grape varieties.
- Optimizing row orientation: The direction of vineyard rows significantly influences the temperature and light exposure on different sides of the vine. Planting rows across the slope, rather than up and down, can reduce soil erosion and optimize sunlight interception in regions like New York's Finger Lakes.
- Modern terracing and restructuring: For steep slopes, modern vineyard terracing, where rows run parallel to the hillside, facilitates management, lowers production costs, and improves occupational safety. This approach creates uncultivated embankments between vine rows. The restructuring of steep-slope vineyards from traditional down-slope rows to contour-wise cross-slope vineyards with greened embankments offers a way to reconcile economic efficiency with biodiversity conservation.

Key Ecosystem services:

- Erosion control
- Water regulation
- Mesoclimate regulation
- Biodiversity conservation
- Habitat provision
- Enhanced species richness
- Reduced production costs
- Improved grape quality
-

Challenges that could arise:

- Erosion on steep slopes: While reorientation can mitigate erosion, very steep slopes (greater than 15-20%) may still require planting up and down hills for machinery, which can increase erosion risk. Abandonment of terraced landscapes also poses a soil degradation hazard.
- Economic viability and high costs: Cultivating steep-slope vineyards is highly labour- and cost-intensive, often leading to abandonment. Although modern terracing aims to lower costs, finding an economically viable and affordable revegetation strategy for the embankments is demanding.
- Resistance to change: Deeply established viticultural traditions and regional image can conflict with the adoption of new, climate-adapted practices.

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HARVEST TIMING ADAPTATION
Description of the EbA strategy: Harvest timing adaptation refers to the strategic adjustment of the date and method of grape harvesting in response to evolving environmental conditions, primarily those driven by climate change. Climate change has notably led to an earlier vegetation period, including earlier bud break, flowering, and ripening. This results in a "strong mismatch between regional climate and crop phenology", requiring winemakers to alter traditional harvest schedules. The goal of this adaptation is to ensure optimal grape quality and maintain sustainable production under new climatic regimes. Adapting harvest timing is a short-term adaptation option within viticulture, alongside other canopy management and winemaking practices. It involves careful monitoring of grape composition, such as grape berry sugar loading dynamic, sugar and acidity levels, which are significantly affected by a shifted ripening period to warmer summer conditions. In the Alpine region optimal ripening traditionally occurs in September, lately already in August, characterized by warm, sunny days and cooler nights. Specific tactical responses can include conducting several harvests by selecting bunches or harvesting at night using machines, particularly when facing a wet ripening period.
Key Ecosystem services: • Optimized grape and wine quality • Reduced risks and enhanced crop health (lower need of pesticides) • Sustainable and cost-effective management
Challenges that could arise: • Grape quality and weather risks: It's increasingly difficult to achieve the perfect balance of sugar and acidity in grapes due to unpredictable weather. An earlier growing season also increases the risk of damage from late frosts in the spring and summer heatwaves causing sunburn on the grapes. • Complex decisions and costs: Pinpointing the new, ideal harvest window is much harder, and there's a lack of reliable predictive models to help guide these decisions. Furthermore, adaptive strategies like harvesting multiple times or using machines at night can be logistically difficult and expensive. • Conflict with tradition: Drastically changing long-established harvest dates can clash with a wine region's traditions, identity, and consumer expectations, potentially facing resistance from both winemakers and the market.

NETS AGAINST HAIL / SUNBURN
Description of the EbA strategy: Nets against hail / sunburn are protective coverings used in viticulture to shield grapevines from adverse weather conditions and intense solar radiation. The use of nets is identified as a potential combined solution for hail, sun, and bird protection. Specifically, "UV protection nets" are described as a measure against increasing sunburn risk for grapes. These nets help grapevines cope with new climate challenges, such as increasing heat and dryness, which can lead to sunburn and damage cells.
Key Ecosystem services: • Yield and quality protection • Microclimate regulation
Challenges that could arise: • Economic costs: The primary challenge highlighted is additional costs associated with the use of protection nets. This includes the initial investment for purchasing and installing the nets, as well as ongoing maintenance. • Material durability and environmental impact: There is an emphasis on choosing reusable nets for protection, indicating concerns about the longevity and environmental footprint of the materials. While not explicitly stated for these nets, the use of plastic wires in other vineyard tools like brush cutters raises concerns about the release of microplastics into the environment. • Logistical and management complexity: Deployment and management of nets over large vineyard areas can be logistically challenging. While not detailed for nets, other canopy management practices require a comprehensive seasonal management strategy. • Potential interference with other practices: Any measure that significantly changes the vineyard environment can lead to unexpected effects on biodiversity or other ecosystem services. For example, habitat creation for wild bees and butterflies is crucial in vineyards, and large physical structures could interfere with such efforts.

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EARLY-WARNING MODELS FOR FUNGAL PATHOGENS
Description of the EbA strategy: Early-Warning Models for Fungal Pathogens are technological tools, often implemented as Decision Support Systems (DSS), designed to assist farmers, particularly in viticulture, in managing plant diseases more sustainably. These models operate on the principle of the "disease triangle," which posits that disease development results from the interaction of a susceptible host plant, a virulent pathogen, and favourable pedoclimatic (soil and climate) conditions. The primary goal of these systems is to provide modern forecasts regarding the timing and intensity of pest and pathogen outbreaks, thereby guiding intervention strategies. For example, the OiDiag-System is specifically used for powdery mildew by estimating initial infestation at the start of the growing season and evaluating weather conditions to determine the optimal timing and duration for fungicide applications. Similarly, Vite.net® is an interactive portal (www.acquavitis.eu) that systematically collects agrometeorological parameters, along with satellite and other spatial data, to interpret information on water stress in vineyards and the water status of soil and plants. This allows for early warning of infective periods for fungal diseases and insects, supporting decisions on when and if phytosanitary measures are needed. Such approaches are crucial for protecting crops like grapevines from major fungal pathogens such as downy mildew (*Plasmopora viticola*), powdery mildew (*Erysiphe necator*), and *Botrytis cinerea* (bunch rot), which can severely degrade grape and wine quality.
Key Ecosystem services: • Increased yield quality and quantity • Disease reduction (lower need for spraying), lower environmental impact • Soil health and biodiversity conservation

Challenges that could arise:

- Accuracy and reliability of forecasts: A major limitation is the difficulty in accessing reliable and accurate weather forecasts, especially for medium-term predictions. This directly impacts the precision of disease risk estimations.
- Microclimate integration: Many existing DSS do not adequately account for microclimatic variations within the vineyard. This is a critical oversight, as high humidity levels in the canopy are known to significantly increase the risk of fungal and bacterial infections.
- Limited scope and integration: Current models may not cover all relevant parasites and pathogens affecting a crop. Furthermore, some DSS struggle to integrate or combine treatments for multiple pest and pathogen threats simultaneously, leading to less comprehensive management strategies.
- Market penetration and adoption: While promising, the penetration of these Decision Support Systems into the agricultural market has been limited, though future opportunities are acknowledged.
- Evolving pathogen resistance: The problem of increasing fungal infestation and resistance to treatments is a continuous challenge, necessitating ongoing development and adaptation of both models and control strategies, including the use of resistant varieties

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HEDGES / ISOLATED TREES / SHRUB PLANTING
Description of the EbA strategy: Hedges, isolated trees, and shrub planting are forms of plant diversification often integrated into agricultural landscapes, particularly vineyards, to enhance ecological functions and promote sustainability. These elements are considered "nature-based solutions" that leverage ecosystem processes to address societal challenges while providing environmental, social, and economic benefits. They act as structure providers of the cultural landscape, typically consisting of rows of various native woody plants or scattered individual trees. This practice, sometimes part of larger agroforestry systems, integrates woody and perennial plants with herbaceous crops and/or animal husbandry, and can involve new plantings of trees or the conservation of existing ones, including dead trees, to create valuable ecological niches.
Key Ecosystem services: • Biodiversity conservation and habitat provision • Microclimate regulation • Soil health improvement • Erosion control • Disease reduction (lower need for spraying), lower environmental impact • Cultural and aesthetic service
Challenges that could arise: • Water competition: While deep-rooted trees can enhance water availability through hydraulic lift, there can still be competition for water between the planted trees/shrubs and the main crop, especially in arid regions, with young vines, or if not carefully managed. • Introduction of pests: The establishment of green infrastructures like hedgerows and trees, while beneficial for biodiversity, could potentially introduce or attract previously unobserved vineyard pests. • Management complexity and costs: Hedges require regular and professional maintenance to ensure their long-term ecological function.


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PERENNIAL FLOWER BEDS
Description of the EbA strategy: Perennial flower beds represent nature-based solutions aimed at enhancing the sustainability and resilience of agricultural landscapes, such as vineyards, by integrating diverse plant communities and woody perennials. These practices increase biodiversity and leverage ecosystem processes to provide a range of environmental, social, and economic benefits. Perennial flower beds typically involve the establishment of species-rich plant communities of native herbs and grasses within agricultural areas, such as vineyard inter-rows or on embankments. These can also include flower strips or "greened embankments" in terraced vineyards, and uncultivated verges and corners at the edges of cultivated areas. The goal is to create long-term, diversified vegetation cover. For vineyard terrace embankments, revegetation with regional seed mixtures, often applied through hydro-seeding, is emphasized to establish and maintain these plant communities.
Key Ecosystem services: • Biodiversity conservation and habitat provision • Soil health improvement and erosion control • Disease reduction (lower need for spraying), lower environmental impact • Microclimate regulation • Cultural and aesthetic value
Challenges that could arise: • Water competition and yield impact: A significant challenge for perennial flower beds (cover crops) is the potential competition for water and nutrients with the main crop, especially in arid regions or with young vines, which can lead to diminished grape yield and quality. Vineyard managers must carefully balance the benefits of cover crops with the risk of water stress in vines. While extensive vegetation management can increase biodiversity and ecosystem services without major negative impacts on grape yield or soil water budget, some studies indicate reduced wine production in organic farming systems that promote biodiversity and pest control. • Management complexity and costs: Perennial flower beds require regular and appropriate management, such as mowing, to maintain floral diversity, prevent scrub invasion, and ensure the availability of nectar and pollen sources throughout the growing season. The selection of optimal mowing dates and techniques, considering nesting periods of endangered bird species, is crucial. Implementing certain revegetation strategies, like hay threshing, can incur high costs. Fertilizer application on embankments might be superfluous or even have an adverse effect on plant species richness in some contexts.


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AGROFORESTRY
Description of the EbA strategy: Agroforestry is an integrated agricultural system that combines traditional farming techniques with forest management, integrating woody and perennial plants with herbaceous crops and/or animal husbandry. This approach aims to create land-use systems that are more efficient, productive, healthy, diversified, and sustainable. The integration of trees, shrubs, annual crops, and animals into vineyards is an ancient practice, particularly in the Mediterranean region. Different types of agroforestry can be distinguished: • Silvo-arable systems involve growing tree species (woody plants, fruit-bearing plants, or others) alongside herbaceous crops. • Forestry and pastoral systems combine livestock with arboriculture, either for wood or fruit production. • Linear systems feature hedges and similar structures at the edges of fields, providing protection for agro-ecosystems and agricultural surfaces. • Riparian belts involve planting tree and shrub species along waterways to protect them from degradation, erosion, and pollution. • Cultivations in the forest primarily focus on non-wood products like mushrooms and berries. Agroforestry emphasizes long-term land-use practices and woodlot management, meeting criteria of being intensive, interactive, and integrated. It is considered a nature-based solution, at the core of developing strong agroecology, aiming to build multifunctional landscapes that provide environmental, social, and economic benefits while enhancing resilience.
Key Ecosystem services: • Soil health improvement and erosion control • Biodiversity conservation and habitat provision • Disease reduction (lower need for spraying), lower environmental impact • Water management • Production and economic diversification • Cultural and aesthetic value

Challenges that could arise:

- Management complexity and labour costs: Implementing agroforestry can require adaptation from the involved workforce, including training for pruning teams and carefulness with machinery. While some systems can be more cost-efficient in terms of pest management and reduced pesticide use, the overall management might require additional effort and costs compared to conventional monoculture.
- Possible yield decreases and economic viability: The transition from conventional to nature-based agriculture may initially lead to lower yields, particularly in the first few years. Agroforestry sites, especially when first implemented or not fully optimized, may be criticized for not producing comparable output to monoculture vineyards. While land-use efficiency can be increased, achieving full potential, such as integrating by-product producing entities like poplar and oak, might not always be realized by local farmers due to specific management systems.
- Resource competition: While trees can enhance water availability, there is a potential for competition for water and nutrients between trees and the main crop, particularly in arid regions or during establishment.


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HABITAT CREATION (E.G., NESTING BOXES, SPECIFIC STRUCTURES)

Description of the EbA strategy:
Habitat creation refers to nature-based solutions designed to establish and enhance ecological niches and structural diversity within agricultural landscapes, such as vineyards, to support biodiversity and ecosystem functioning. This can involve a variety of elements, ranging from small-scale structures to broader landscape modifications.
Specific examples of habitat creation include:
• Simple ecological niches: Converting economically unviable areas into flower-rich or fallow fields. This also encompasses introducing elements like stone piles, sand lenses, open soil areas, and deadwood.
• Structural elements: Implementing hedges, dry stone walls, and stone barriers. Hedges and shrub rows made of native woody plants are considered their own ecosystem. Dry stone walls are traditional masonry works built without or with little binder, using local materials, and integrated into terraced systems.
• Nesting and shelter structures:
  o Nesting boxes and insect hotels for wild bees, birds, and other pollinating insects. These can be simple bundles of reeds, wood with drilled holes, or more complex wooden frames with compartments and various filling materials like bamboo rods, hollow stems, logs, or pine cones.
  o Towers of life are multi-level structures designed to provide different living, hiding, and overwintering spaces for various animals, from hedgehogs, reptiles, and amphibians at the base to bumblebees, wasps, spiders in upper levels, and bird nesting boxes or raptor perches at the top. Old transformer stations or unused vineyard huts can be creatively repurposed into these structures.
• Tree planting: Introducing new trees or maintaining isolated trees (including fruit trees) provides habitat and shade.
• Water features: Creating small, flat-water bodies can promote biodiversity by providing a fluid source for birds and insects.
• Landscape-scale diversification: Increasing non-crop habitats such as forests, grasslands, and hedgerows, and enhancing overall landscape heterogeneity and connectivity. This also includes the revegetation of terrace embankments created by modern vineyard terracing, which offers significant non-cropped areas.

Key Ecosystem services: • Biodiversity conservation and habitat provision • Disease reduction (lower need for spraying), lower environmental impact • Soil health improvement • Erosion control • Cultural and aesthetic value
Challenges that could arise: • Management and maintenance complexity: Nesting structures require proper routine and periodic maintenance to remain functional and prevent the accumulation of parasites. • Material degradation: Natural filling materials in "bug hotels" degrade over time and must be replaced, especially wooden components, which should not be chemically treated. • Labour and cost: While some practices may reduce other costs (e.g., less pesticide use), the creation and ongoing maintenance of diverse habitats can involve additional effort and costs. • Unpredictable occupancy: It is often difficult to predict which species and how many individuals will occupy artificial shelters. If a shelter is not visited, it might need to be "triggered" by being temporarily placed in a more biodiverse area. • Design flaws: Poorly designed or excessively large/concentrated nests can paradoxically increase mortality in solitary bees due to parasitism.


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USE OF PERENNIAL PLANTS FOR DIVERSE FAUNA
Description of the EbA strategy: The use of perennial plants for diverse fauna involves implementing nature-based solutions to integrate and maintain varied plant life within agricultural systems, such as vineyards, and in the surrounding landscape. This can range from within-field strategies to broader landscape diversification. Specific examples include: • Within-field plant diversity: Extensive management of spontaneous vegetation, sowing diverse cover crops, or planting flower strips in interrow. This often involves perennial grasses and herbs. • Agroforestry systems: Integrating trees with crops or intercropping systems. • Landscape-scale diversification: Increasing non-crop habitats such as forests, grasslands, and hedgerows, which are considered semi-natural habitats. • Perennial aromatic plants: Species like oregano and thyme can be intercropped due to traits like flat-growing, shade-tolerance, and adaptation to dry conditions. • Fallow areas: Converting economically unviable areas into flower-rich or fallow fields, which can develop into species-rich dry grasslands with patience.
Key Ecosystem services: • Biodiversity conservation and habitat provision • Disease reduction (lower need for spraying), lower environmental impact • Soil health improvement • Erosion control • Cultural and aesthetic service

Challenges that could arise:

- Competition with the vines: Water and nutrient competition between perennial cover crops and the main crop, such as vines, can be significant. This can lead to water stress in vines, especially in arid regions with limited rainfall, and may reduce grape yield and quality. Gramineous species, for example, have high competitiveness and a notable "nitrogen hunger," potentially outcompeting vines for nutrients. A proper choice and management of cover crops are crucial to avoid disservices from severe competition.
- Management and maintenance complexity: Establishing perennial vegetation on challenging sites like steep, south-exposed terrace embankments can be difficult due to harsh environmental conditions such as extreme heat and drought, which hinder seedling recruitment and initial plant establishment. Long-term maintenance through regular mowing with subsequent biomass removal is necessary to maintain plant species richness and prevent scrub invasion. Incorrect or poorly timed mowing can reduce nutritional resources for fauna. Some specific perennial plants, like piloselle, may suffer from competition in their early developmental stages despite their later herbicidal properties. The creation and ongoing management of diverse perennial habitats can involve additional labour and costs.
- Effectiveness and specificity: The effectiveness of management options on biodiversity is dependent on the specific taxonomic groups and their functional traits. Spontaneous flora may develop randomly and provide limited ecosystem services compared to intentionally selected species or mixtures. There is a need for region-adapted seed mixtures, as commercial or generic mixtures may perform poorly in terms of vegetation cover and plant diversity in specific contexts.
- Socio-economic barriers: Economic concerns, such as the risk of lower yields and missing short-term returns, are significant barriers to the systematic adoption of cover crops. The long-standing threats of farmland abandonment and intensification continue to challenge nature-friendly farming systems.

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USE OF AROMATIC PLANTS FOR INTERCROPPING
Description of the EbA strategy: he use of aromatic plants for intercropping involves integrating specific perennial, flat-growing, and shade-tolerant aromatic plant species, such as oregano (*Origanum vulgare*) and thyme (*Thymus vulgaris*), into agricultural systems, often between the rows of main crops like grapevines. These plants are typically adapted to dry and warm pedoclimatic conditions. Agronomic cultivation handbooks suggest that aromatic plants have low to moderate needs for soil resources, can grow between 0.3 to 1.0 meters during blossom, and offer profitable cultivation periods of five to ten years with up to two harvests annually under favourable climates. This practice is seen as a nature-based solution to diversify cropping systems, aiming to combine short-term economic returns from the aromatic plants with various environmental benefits.
Key Ecosystem services: • Biodiversity conservation and habitat provision • Disease reduction (lower need for spraying), lower environmental impact • Soil health improvement • Erosion control • Cultural and aesthetic service
Challenges that could arise: • Competition with the Main Crop: A significant challenge is the competition for water and nutrients between the aromatic intercrops and the main crop. Studies have shown that intercropping can lead to consistently lower gravimetric soil moisture and reduced levels of plant-available ammonium-nitrogen, potassium and phosphorus in the topsoil. This competition, particularly for water, can result in insignificant yield losses for the main crop. For instance, oregano plants, due to their wider growth and notably higher below-ground root biomass, can exert a stronger impact on soil resources compared to thyme. Severe competition can also lead to other "disservices" such as reduced grape yield and quality, or even the unintentional provision of habitats for pests and pathogens. • Establishment and management intensity: Establishing aromatic plant seedlings can be challenging, especially in harsh conditions. A heavy rain event, for example, resulted in the translocation of soil and newly planted intercrop seedlings, with thyme-diversified rows experiencing the highest soil losses. Poor establishment, exacerbated by dry conditions, necessitated re-planting and manual irrigation, increasing the initial management intensity and labour requirements for these diversification treatments.


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PREDATOR MITE MONITORING / ARTHROPOD SURVEYS
Description of the EbA strategy: Predator mite monitoring / Arthropod surveys involve the systematic observation, sampling, and assessment of arthropod communities, including beneficial organisms like predator mites, within agricultural ecosystems such as vineyards. This practice is crucial for understanding the species composition and population dynamics of these communities and their interactions with the environment and management practices. These surveys often aim to characterize above- and below-ground biodiversity and evaluate the effectiveness of various agricultural strategies, such as cover cropping or canopy management, on both pest and beneficial arthropods. Specific examples include monitoring wild bees and butterflies as ecological indicators.
Key Ecosystem services: • Disease reduction (lower need for spraying), lower environmental impact • Pollination • Biodiversity conservation • Soil health improvement

Challenges that could arise:

- Competition and disservices: Management practices intended to boost beneficial arthropods, such as maintaining non-mown alleyways, can also inadvertently promote vineyard pests, leading to trade-offs in pest control. For example, increased pollen availability benefiting predatory mites can also lead to a higher presence of pests like American grapevine leafhoppers.
- Impact of Intensive agricultural practices: Intensive agricultural practices, including tillage and frequent passage of heavy equipment, are major drivers of insect biodiversity loss. Tillage, in particular, can destroy the nests of ground-nesting bees, significantly reducing their abundance. The removal of flowering plants in vineyards to reduce water competition with vines also removes nutritional resources for beneficial insects, especially in late summer.
- Methodological limitations and data gaps: Some sampling methods, like pan trap sampling, can provide unreliable measures of bee abundance, particularly when there are differences in flower cover, posing a challenge for accurate assessment.
- Management of habitats for beneficials: While artificial nests and shelters for insects can enhance biodiversity, improper maintenance can lead to the accumulation of parasites, potentially turning these aids into "deadly traps" for the insects they are meant to help.
- Poor dispersal abilities of certain taxa: Arthropod species with poor dispersal abilities are more significantly affected by local farming practices than by landscape-scale management, making local monitoring and targeted interventions especially critical.

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PROTECTED FORESTS / VEGETATION COVER
Description of the EbA strategy: Protected forests and vegetation cover refer to a diverse array of natural and managed plant communities, ranging from extensive forest areas to semi-natural habitats like grasslands, hedgerows, and integrated agricultural systems such as cover crops and agroforestry. These elements are considered nature-based solutions designed to enhance the sustainability and resilience of landscapes, particularly in areas subject to intensive agriculture like vineyards. Such cover is vital for maintaining ecological networks and functional biodiversity across a territory. Protected forests, specifically, are woodlands managed to safeguard human populations and infrastructure from natural hazards and are seen as essential for environmental defence.
Key Ecosystem services: • Biodiversity conservation and habitat provision • Carbon sequestration • Microclimate regulation • Water cycle regulation • Soil health improvement • Erosion control • Natural hazard protection • Cultural and aesthetic value • Provisioning service

Challenges that could arise:

- Impacts of climate change on forests: Mountain forests are increasingly vulnerable to extreme events such as wind gusts, prolonged dry periods, forest fires, floods, and avalanches, as well as pest diseases, all of which are projected to intensify with ongoing climate change. Intense rainfall can exacerbate abiotic damage, including fires and breakage from wind or snow.
- Sub-optimal forest management: Damage to forests (e.g., from fires or storms) can often result from non-optimal management practices, such as failing to remove older, "over-mature" trees.
- Risks from species selection: Reforestation efforts using drought-resistant species, like black pine, can introduce new problems such as slow decomposition rates or mass infestations by pests like processionary moths.
- Trade-offs in agricultural systems: While vegetation cover offers numerous benefits, in arid regions, cover crops can compete with main crops (e.g., grapevines) for limited water resources, potentially causing water stress if not carefully managed.
- Habitat degradation: General habitat degradation negatively affects the distribution and stability of plant species and their communities.
- Weed management: The competition for water between vines and undesirable vegetation can lead to the removal of flowering plants, thereby reducing floral resources for beneficial insects.
- Land abandonment and succession: Demographic aging and the abandonment of rural and alpine territories can lead to a reduction in cultivated areas, which are then often overtaken by scrub woods that are difficult to remove due to existing forest and landscape regulations. This poses obstacles to re-establishing productive agricultural activities.
- Economic viability: Traditional farming in marginal areas, often characterized by High Nature Value farming, faces significant social and economic difficulties, including low remuneration and challenges in mechanization.


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TERRACE RESTORATION & NEW TERRACING SYSTEMS
Description of the EbA strategy: Terrace restoration and new terracing systems involve the physical reshaping and management of sloping land, often in agricultural areas like vineyards, to create a series of level or gently sloping platforms (terraces) supported by retaining walls or embankments. These practices are considered nature-based solutions aimed at enhancing the sustainability and resilience of landscapes. Traditional dry-stone walls are a key component of these systems, built without or with minimal binders using local materials, and are dynamic entities that respond to changes in land use, population needs, and climatic conditions. Modern vineyard terracing, where rows run parallel to the hillside, is a contemporary approach designed to make viticulture on steep slopes more economically viable.
Key Ecosystem services: • Soil conservation • Erosion control • Water management • Biodiversity conservation and habitat provision • Cultural and aesthetic value
Challenges that could arise: • Economic unviability: Traditional terraced vineyards often become unprofitable due to high management costs, difficult labour conditions, and an aging workforce. Restoring these areas is expensive and requires a sustainable economic plan to succeed. • Land abandonment and overgrowth: Rural depopulation leads to abandoned terraces, which are quickly overgrown by forests. Regulatory hurdles can prevent the clearing of this growth, hinder restoration efforts and increasing soil erosion risks. • Mechanization barriers: The steep, dense layout of traditional vineyards makes using machinery nearly impossible. This forces a reliance on costly manual labour, which in turn drives further abandonment. • Ecological risks: In arid regions, cover crops can compete with vines for scarce water. Restoration projects can fail due to improper seed selection or extreme weather events, which can worsen erosion. Furthermore, high nutrient use during revegetation can harm plant biodiversity. • Social and policy hurdles: Fragmented land ownership complicates large-scale restoration projects. A lack of specialized skills, capital, and institutional support also presents significant barriers. The core challenge is balancing the economic viability of farming with essential conservation goals.

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BIO-ENGINEERING
Description of the EbA strategy: Bio-engineering in the context of sustainable agriculture, particularly viticulture, refers to the use of biological inputs and processes to enhance plant and soil health, improve crop performance, and strengthen ecosystem functioning. It involves leveraging natural mechanisms within agroecosystems, rather than relying solely on conventional chemical inputs. This approach emphasizes practices that stimulate natural processes to boost nutrient uptake and efficiency, improve tolerance to abiotic stresses, and enhance crop quality. It is distinct from traditional fertilizers and crop protection products, as bio stimulants, a key component, primarily act on plant vigour rather than directly combating pests or diseases. Broader concepts like "soil ecological engineering" also fall under this umbrella, aiming for agricultural sustainability through biodiversity and soil processes.
Key Ecosystem services: • Soil health and fertility enhancement • Disease reduction (lower need for spraying), lower environmental impact • Improved tolerance to abiotic stress • Increased yield quality and quantity • Improved water use efficiency • Biodiversity support

Challenges that could arise:

- Potential alteration of soil microbiomes: The application of microbial BCAs and their subsequent colonization in vineyard soils could potentially alter the composition of existing soil microbiomes, which may have unforeseen implications for overall soil functioning and health.
- Regulatory and certification complexities: While bio stimulants are allowed in organic agriculture under certain EU regulations (Reg (EU) No. 2019/2164), and specific contaminant limits are set, there can be challenges with evolving regulatory frameworks (e.g., some bio stimulants were previously considered pesticides). The expenditure and cost associated with obtaining certifications, such as "Biodiversity Friend," can also be a critical aspect for farms.
- Economic viability and stakeholder adoption: There's a need for innovation from both public and private sectors to ensure that sustainable management practices, including bio-engineering, can be implemented while maintaining or even improving profit margins for farmers and winemakers. Integrating stakeholders' perspectives is crucial for the adoption and efficiency of these solutions, and dedicated long-term research infrastructures (like living labs) are needed for co-designing and assessing locally tailored solutions.
- Difficulty in upscaling and modelling: Much of the existing knowledge comes from empirical studies in specific contexts. There is a strong need to develop models (statistical and mechanistic) to forecast the impacts of bio-engineering solutions and to upscale the consequences of their large-scale expansion in real landscapes.

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DRY-STONE WALLS
Description of the EbA strategy: Dry-stone walls are traditional masonry structures constructed without the use of binders like mortar or cement. These walls are typically built using locally sourced stones, often derived from land cultivation or quarries. The construction technique involves laying a foundation of large, regular blocks, followed by multiple layers of coarse stones, with minute stones used to fill interstices and stabilize the structure. The height and thickness of the wall vary according to the original slope, tapering towards the top. A key feature is the dry laying, which facilitates the drainage of rainwater, and often includes a crushed stone counter-wall behind it to enhance drainage and reduce hydrostatic pressure from the embankment. Dry-stone walls are not isolated features but are integral parts of larger systems, such as terraces, defining and modifying landscapes over centuries through a slow integration between human activity and nature. They are considered "living" structures due to their ecological functions and interactions within the environment. These walls, along with other structural elements like hedgerows and stone heaps, create valuable ecological niches in agricultural landscapes, particularly in viticulture.
Key Ecosystem services: • Hydro-geological function • Erosion control • Microclimate regulation • Biodiversity support • Enabling cultivation on steeply sloping land • Cultural and historical heritage • Aesthetic and recreational service
Challenges that could arise: • Economic and labour challenges: The construction and upkeep of dry-stone walls are labour-intensive, requiring skilled craftspeople, which often makes them less economically viable than modern concrete alternatives. There is a lack of quantitative data on the socio-economic consequences for farmers, and traditional maintenance may not align with current economic pressures. • Technical and material sourcing: Proper construction is critical for durability, demanding correct techniques and solid foundations. Sourcing suitable, locally-appropriate stone can present logistical challenges, and walls intended to support infrastructure require professional engineering designs. • Abandonment and degradation: Agricultural intensification and land abandonment threaten traditional landscapes featuring dry-stone walls. The adoption of modern materials has led to the neglect of these structures, which are also vulnerable to damage from farming activities and collapse, leading to the degradation of terraced landscapes.


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