Vineyard regeneration and aging in Hungary: a spatial analysis based on 2020 data

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Abstract

The age structure of vineyards fundamentally determines the sustainability of winemaking, the economic stability of production, and the future competitiveness of wine regions (Costantini–Bucelli, 2014; Priori et al., 2019). Hungarian viticulture builds on centuries of tradition, yet global economic, social, and environmental challenges—such as climate change, market competition, and demographic shifts—have redefined the framework within which the sector operates (Matthews, 2013; Lencucha et al., 2020).

The aim of this study is to examine the age structure of Hungarian vineyards using settlement-level data from 2020. The analysis investigates the spatial distribution of four age groups (0–3 years, 3–9 years, 10–29 years, 30+ years) at national, wine region, wine district, and municipal levels. Special attention is given to the Danube Wine Region, which in recent decades has exhibited the most dynamic vineyard renewal processes. The methodology combines descriptive statistical analysis, cartographic visualization, and spatial autocorrelation techniques (Deloire et al., 2003; Bramley, 2020).

The novelty of the research lies in its detailed, settlement-scale approach, which enables the identification of spatial patterns of vineyard rejuvenation and aging. The findings highlight those wine districts where vineyard stocks are undergoing dynamic renewal - most notably in the Danube Wine Region - as well as areas where the predominance of older plantings threatens sustainability. The study contributes to the assessment of vineyard sustainability and provides guidance for development and support policies aimed at securing the long-term competitiveness of Hungarian wine regions (Máté, 2008; Schwarz, 2003; Kovács, 2010).

Keywords: vineyard age structure, viticulture, vineyard renewal, regional disparities of wine districts, renewal index

JEL classification: Q15, Q18, Q19, R11

Introduction

Viticulture and winemaking have for centuries been defining elements of Hungary's economy, culture, and land use. Hungarian wines have been present on international markets since the Middle Ages, and after the phylloxera crisis the country's viticulture experienced renewed momentum—particularly on the sandy soils of the Great Hungarian Plain, where the pest caused relatively little damage (Bulla & Mendöl, 1947). From the turn of the 19th and 20th centuries onward, a dual structure emerged: high-quality wines from Transdanubia and the Northern Uplands on the one hand, and mass-production wines from the Great Plain on the other (Schwarz, 2003; Kovács, 2010). Historical traumas, socialist collectivization, and the economic transformations following the political transition all had a profound impact on vineyard structures and the development of wine markets (Schwarcz, 2003).

In recent decades, globalization, shifting consumer preferences, and global crises - such as the COVID-19 pandemic and climate change - have posed new challenges for Hungarian viticulture (Matthews, 2013; Lencucha et al., 2020). Climate change is increasingly recognized as a critical factor reshaping grape-growing suitability, yield variability, and wine quality worldwide, requiring site-specific adaptation strategies and new management approaches (Santos, 2020; van Leeuwen et al., 2024). Intensified market competition, the growing emphasis on quality production, and the necessity of sustainable farming practices are all factors directly influencing the age structure of vineyards. At the same time, demographic changes - particularly youth outmigration and labor shortages - also represent serious challenges for the sector. Similar conclusions have been drawn in broader regional labor market analyses, where the development of human capital has been identified as a key determinant of resilience and competitiveness (Győri, 2021a, 2021b).

The age and renewal dynamics of vineyards are decisive for the sustainability and competitiveness of winemaking. A lack of young plantations inevitably leads to the aging of vineyards, declining yields, and weakening market positions (Costantini–Bucelli, 2014; Priori et al., 2019; Bramley, 2020). Recent research emphasizes that renewal also depends on varietal diversity and the deliberate selection of grapevine genotypes better suited to evolving climatic conditions, which may explain regional differences in renewal intensity (Baltazar et al., 2025).

In addition to national and regional comparisons, this study places particular emphasis on the *Danube Wine Region,* one of the most dynamically changing areas of Hungarian viticulture, which displays distinctive patterns of vineyard rejuvenation.

The aim of this research is to map the age structure of Hungarian vineyards using municipality-level data from 2020. The results contribute to assessing the long-term sustainability of viticulture, identify hotspots of vineyard renewal and areas lagging behind, and provide guidance for policy-makers in support and regional development. The novelty of the study lies in its settlement-level analysis, which allows for a more detailed picture of the future competitiveness of Hungary's wine regions.

Materials and Methods

The research was based on the 2020 municipality-level vineyard database compiled by the Hungarian Central Statistical Office (KSH) through a full census. The dataset contains the distribution of vineyards by age groups at the settlement scale, thus enabling a detailed examination of age-structure characteristics (Hungarian Central Statistical Office, 2021). Four age categories were distinguished: 0–3 years, 3–9 years, 10–29 years, and over 30 years, each expressed as a proportion of the total vineyard area of a settlement. The analysis explored the spatial distribution of these groups at national, wine region, wine district, and municipal levels.

As a first step, descriptive statistics were calculated. For each settlement, mean, median, and standard deviation values were determined for all four age categories. Additionally, the characteristic proportions were computed for each wine district. To illustrate national-level distributions, histograms were prepared, while boxplots were used to capture differences across wine districts.

Statistical analysis was complemented by cartographic visualization. In QGIS, four separate thematic maps were created, representing the proportion of 0–3, 3–9, 10–29, and 30+ year-old vineyards at the settlement scale. To improve interpretability, quantile classification was applied, ensuring balanced visual representation. Furthermore, a dominant age group map was compiled, assigning each settlement to the category that represented the largest share of its vineyard area. This

method effectively demonstrates which vineyard age groups dominate in different parts of the country.

Vineyard renewal was further analyzed using a composite indicator, the *Renewal Index,* which compares the proportion of young vineyards (0–9 years) to that of old vineyards (30+ years). The value of the index indicates whether the vineyard stock of a settlement is oriented toward rejuvenation or aging. The spatial representation of this index reveals territorial differences in renewal activity. In addition, a *Rejuvenation Rate* (share of 0–9 year-old vineyards relative to the total stock) was calculated, along with a *Balance Index* (Shannon diversity), measuring the degree of heterogeneity in the age structure of vineyards within each settlement.

To uncover spatial relationships, autocorrelation analysis was performed. Global Moran's I was first applied to measure the overall spatial arrangement of young (0–9 years) and old (30+ years) vineyards nationwide. Subsequently, the Local Moran's I (LISA) method was used to identify local clusters. The resulting hotspot–coldspot maps highlighted areas where young vineyards are concentrated (HH clusters) and those characterized by the absence of renewal (LL clusters). Transitional zones (HL, LH) were also identified, indicating mixed spatial structures.

The methodological framework thus enables both numerical and visual comparison of wine regions, as well as an assessment of the spatial sustainability of vineyards. Its purpose is to identify areas where vineyard rejuvenation is successfully taking place, as well as those where the predominance of aging vines poses a potential risk to the future of wine production.

Results

Based on national averages, the Hungarian vineyard stock in 2020 was predominantly composed of middle-aged (36%) and old (43%) plantations. Young vineyards (0–3 years) accounted for only 4.5% on average, while those aged 3–9 years represented 16.7%. Median values underscore this concentration even more strongly: in more than half of all municipalities, there were no vineyards in the 0–3 year category, and the share of 3–9 year-old plantations was typically only around 5%. The high standard deviations—particularly in the middle-aged and old categories—indicate substantial regional variation. In certain wine districts, the vineyard stock is markedly aged, while in others, young plantations appear at proportions well above the national average (Table 1).

Table 1. Descriptive statistics of vineyard age groups in Hungary (2020)

Age group (years)	Mean (%)	Median (%)	Standard deviation (%)
0–3	4,5	0,0*	High
3–9	16,7	5,4	Moderate
10–29	36,0	29,5	High
30+	42,8	37,8	High

**The median value of 0–3 year-old vineyards is zero because more than half of the Hungarian settlements have no vineyards in this age category. This indicates a high spatial concentration of young plantations and suggests that vineyard renewal occurs only in a limited number of regions. The skewed distribution reflects the structural imbalance of the national vineyard stock, where the majority of the planted area consists of middle-aged and old vines.*

Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations.

Viticulture in Hungary is highly concentrated both spatially and structurally (Figure 1). In the majority of municipalities, the share of young vineyards (0–3 years) and those aged 3–9 years remains low, in most cases below 10%. This indicates that, at the national level, substantial vineyard renewal takes place only in relatively few locations. At the same time, in some municipalities the proportion of young vineyards reaches or even exceeds 20–30%, pointing to active replanting processes (Figure 1).

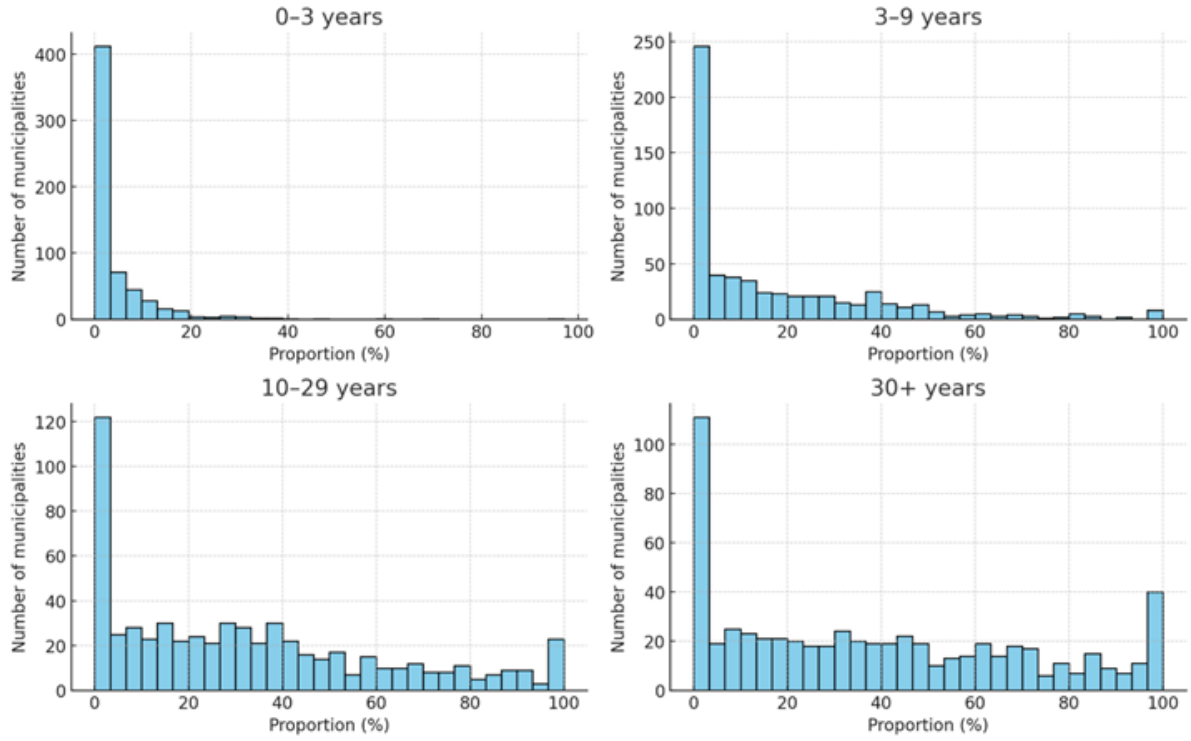

Figure 1 National distribution of vineyards by age group at the municipal level (2020) – Wine district municipalities only

Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations.

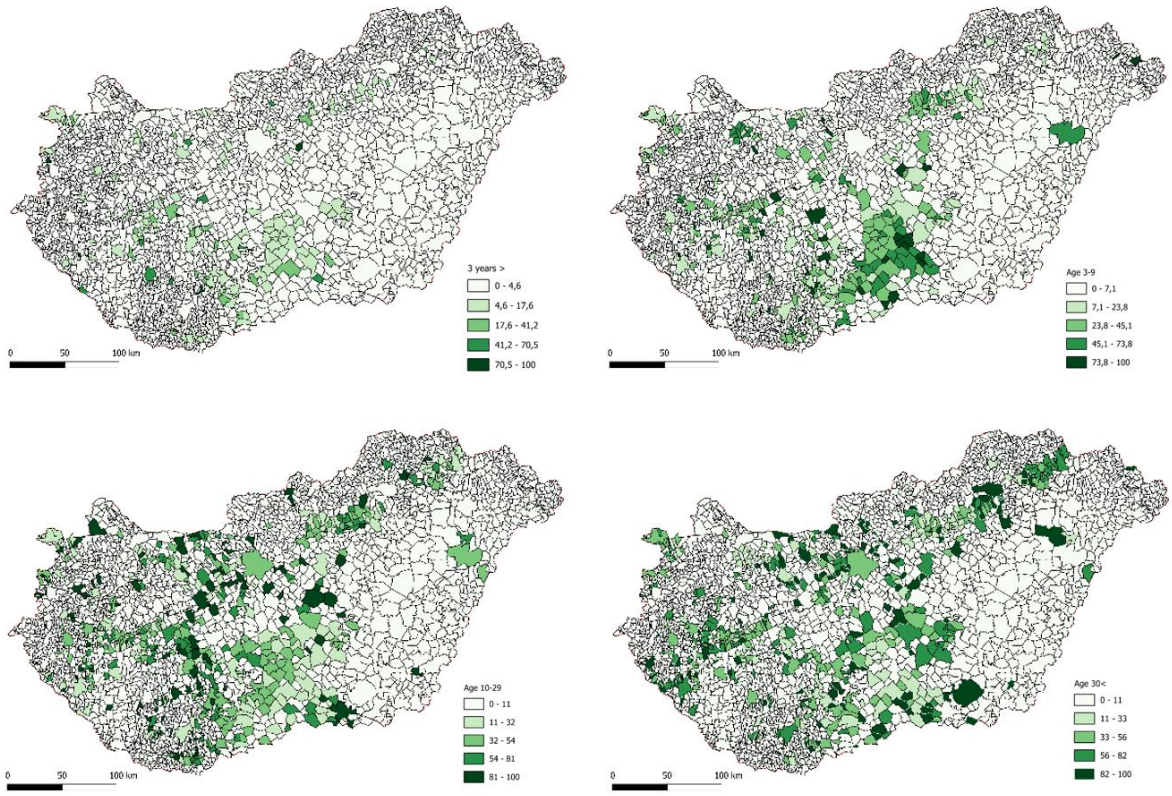

Figure 2 Distribution of vineyard age groups at the municipal level (2020) – Wine district municipalities only (%)

Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations and cartographic representation.

In contrast, the middle-aged (10–29 years) and old (30+ years) categories are clearly dominant: in most municipalities, the vineyard stock belongs primarily to these two age groups. The peaks of the histograms indicate that in many settlements the share of middle-aged and old vineyards falls between 30–60%, and in several cases exceeds 70%.

Hungary's vineyard stock is therefore aging, with young plantations present only in limited numbers and concentrated in specific areas. From the perspective of long-term sustainability, this trend poses a challenge, as vineyard renewal is taking place with sufficient intensity in only a small number of municipalities.

In most wine districts, vineyards over 30 years old dominate, while the presence of young plantations is highly variable across space (Figure 3). In the large wine districts of the Danube Wine Region (Kunság, Csongrád, Hajós–Baja), the proportion of younger vineyards (0–9 years) is higher than the national average. This indicates that replanting and renewal processes are more actively pursued in these areas. At the same time, the variation is considerable: in some municipalities rejuvenation is strong, while in others aging vineyards continue to dominate.

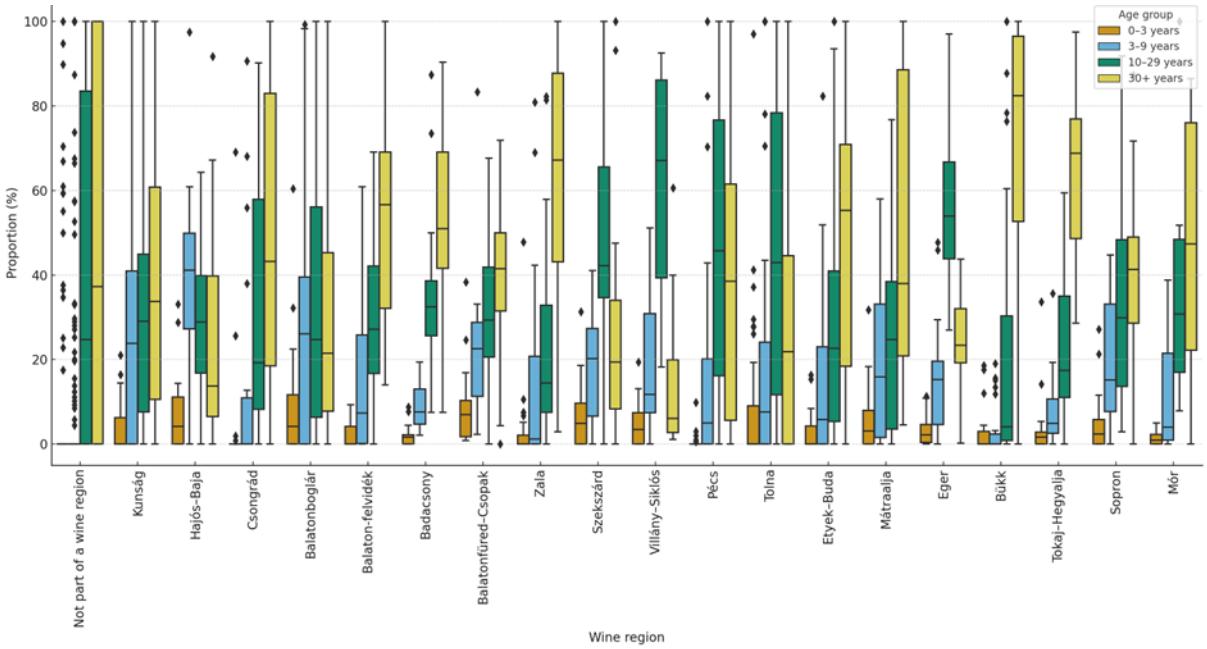

Figure 3 Distribution of vineyard age groups across Hungarian wine districts (2020)
Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations.

By contrast, in several Balaton and northern wine districts (e.g., Badacsony, Balaton Uplands, Tokaj), the share of young vineyards is lower, and old plantations over 30 years dominate. This structure reinforces the problem of aging, which in the long run poses a risk to the sustainability of production.

An intermediate pattern can be observed in the Mátra, Eger, and Balatonboglár districts, where the presence of young vineyards is significant, yet the middle-aged stock (10–29 years) is also strong. These areas present a mixed picture, with the maintenance of older vineyards occurring alongside active replanting processes.

When examining the *average age of vineyards across districts,* the territorial differentiation of Hungary's vineyard stock becomes clearly visible (Figure 4). In the Danube Wine Region, the Kunság and Hajós–Baja districts display an average age considerably below the national mean, reflecting a higher share of younger plantations and more dynamic renewal activity. In contrast, Tokaj, the Balaton Uplands, and Somló contain the oldest vineyards in the country, indicating the lack of replanting and the persistence of traditional vineyard structures.

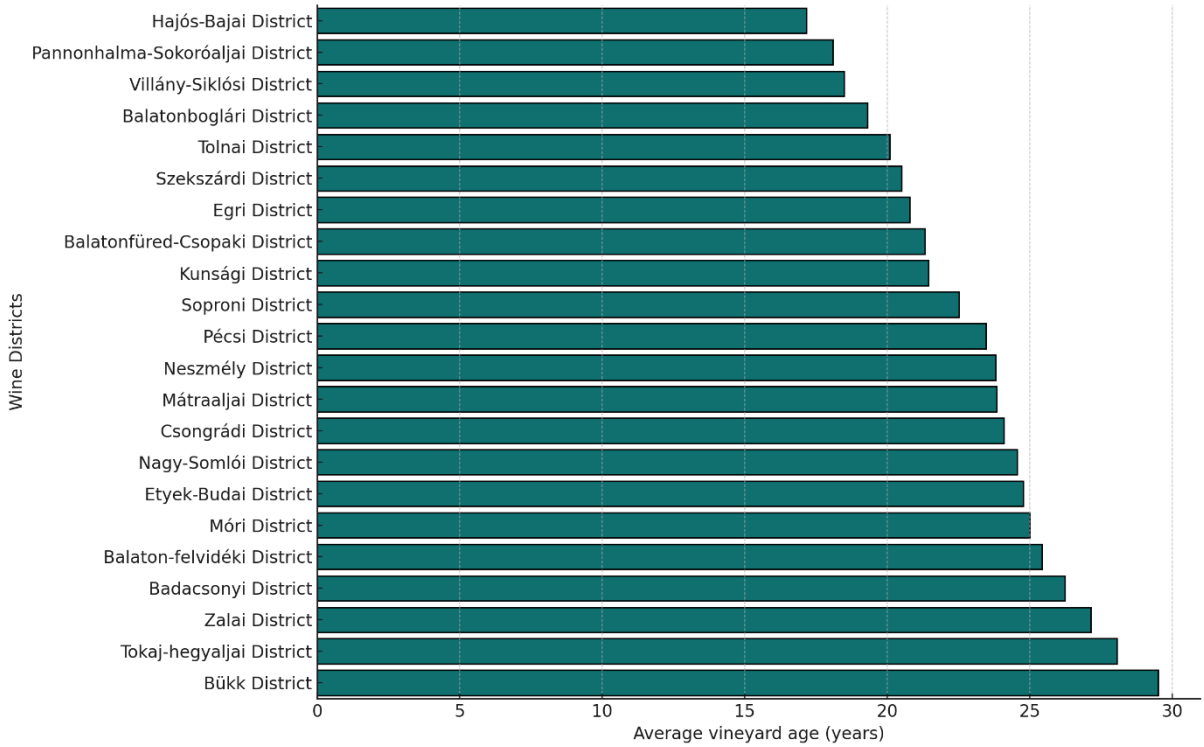

Figure 4 Average age of vineyards across Hungarian wine districts (2020), weighted by vineyard area

Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations.

Other wine districts occupy an intermediate position: here the average vineyard age typically ranges between 20 and 25 years. This indicates a more balanced age structure, yet the risk of aging also persists in the long term.

The differences can be attributed to the fact that Hungarian wine districts follow distinct strategies in vineyard planting and maintenance, which are also influenced by available support schemes and market opportunities.

The three districts of the Danube Wine Region—Kunság, Hajós–Baja, and Csongrád—belong nationally to the group with younger vineyard stocks. According to the bar chart, the Kunság District has the lowest average age, reflecting both the renewal of its large vineyard area and ongoing planting activity. The Hajós–Baja District also shows a younger structure, though with a slightly higher average age. In the Csongrád District, the average vineyard age is somewhat higher, but still remains below the national average.

In the next stage of the analysis, the *Vineyard Renewal Index* was examined. This indicator is defined as the ratio of young vineyards (0–9 years) to old ones (30+ years). It allows for the identification of municipalities where the vineyard stock is undergoing rejuvenation as opposed to those experiencing aging. The results of this analysis are presented in Figure 5.

Based on the national distribution, substantial spatial differences are observable. A number of municipalities—primarily in Southern Transdanubia, the southern part of the Danube–Tisza Interfluve, and several areas of the Northern Uplands—possess exclusively old vineyard stocks, with a Renewal Index value of 0. This category is particularly critical, as it indicates the complete absence of new plantings and, in the long term, suggests the decline of viticulture in these areas.

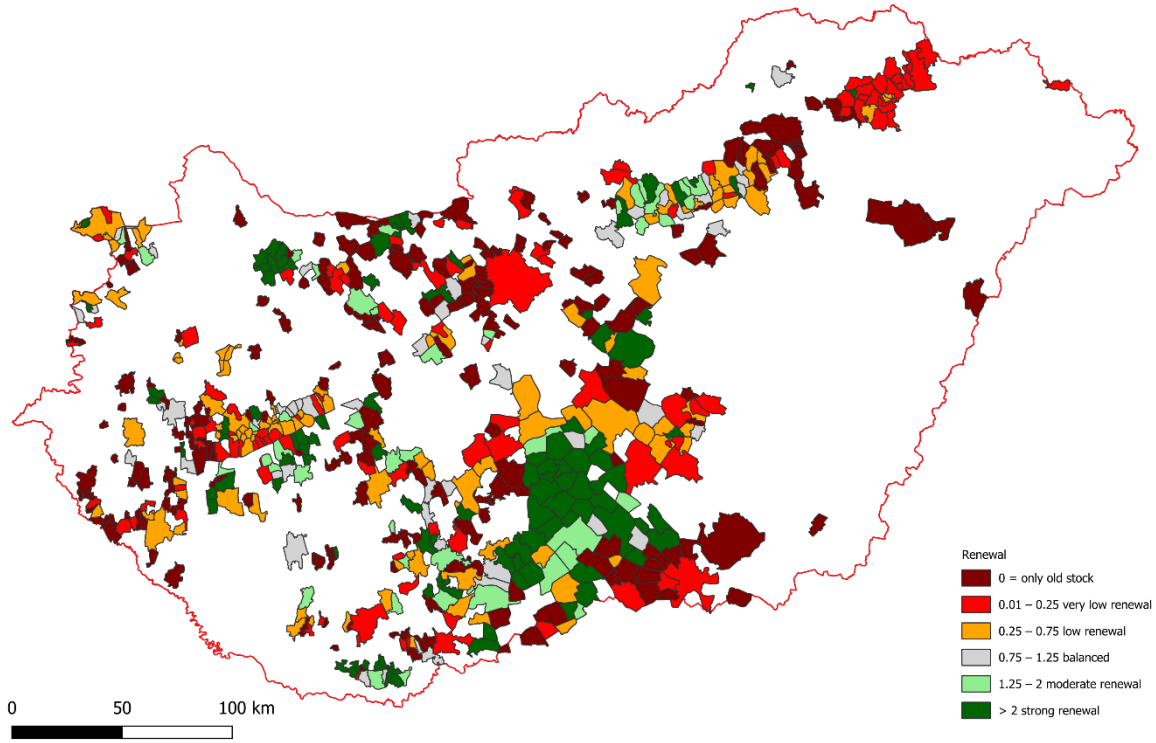

Figure 5 Vineyard Renewal Index at the municipal level (2020)

Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations and cartographic representation.

Municipalities classified into the *"very low renewal" (0.01–0.25)* category appear in a mosaic-like pattern across the country. Although some replanting can be observed in these areas, its extent falls far short of the proportion of old vineyards. This situation foreshadows a widespread problem in many Hungarian wine districts: the gradual but insufficient pace of vineyard renewal.

The *"low renewal" (0.25–0.75)* category occurs primarily in Western Transdanubia, around Lake Balaton, and in the central part of the Great Plain. In these municipalities, the share of young vineyards is already visible, yet old plantations continue to dominate.

The *"balanced structure" (0.75–1.25)* is relatively rare. In such municipalities, the proportion of young and old vineyards is roughly equal, suggesting a more sustainable structure, although in most cases this represents a transitional state.

The *"moderate renewal" (1.25–2)* category is found mainly in the Southern Great Plain, in parts of Csongrád, Békés, and Bács-Kiskun counties. These municipalities exhibit active replanting processes, with the share of young vineyards exceeding that of old ones.

The *"strong renewal" (>2)* category is likewise concentrated in the Southern Great Plain, particularly around Szeged and in southern Bács-Kiskun County. This reflects the most dynamic transformations: the age structure of vineyards is shifting, and the significant dominance of young plantations may ensure the long-term sustainability of viticulture.

The analysis shows that the overwhelming majority of Hungarian vineyards consist of old plantations, with renewal rates negligible in many regions. A sharp territorial contrast emerges: while

aging dominates in many wine districts of the Northern Uplands and Transdanubia, municipalities of the Southern Great Plain display especially vigorous renewal processes.

Balanced structures are rare; instead, the national picture is polarized—either predominantly old vineyards or exceptionally strong rejuvenation. This suggests that the sustainability of vineyards is highly differentiated regionally: in some wine districts urgent intervention is needed, whereas others present dynamic examples of renewal.

Compared to the national average, the *Danube Wine Region* (Kunság, Csongrád, Hajós–Baja) exhibits the most favorable structural dynamics, as most municipalities indicating moderate or strong renewal are concentrated here.

The *Kunság District,* the largest wine district in the country, shows a particularly heterogeneous pattern. In its central and southern municipalities (e.g., Kecskemét, Kiskőrös, Izsák), the renewal index often exceeds 1.25, indicating moderate or strong rejuvenation. This nationally outstanding dynamism is primarily due to the district's large-scale production structure, which allows for rapid replanting. However, in the northern and peripheral parts of the district, several municipalities show low or very low renewal, reflecting the differentiated character of the stock.

The *Csongrád District* (e.g., Csongrád, Hódmezővásárhely and surroundings) also displays one of the most dynamic renewal processes in the country. In many municipalities, the index exceeds 2, indicating strong rejuvenation. This suggests that the young vineyard stock has gained significant dominance over the old plantations, potentially securing the long-term sustainability of viticulture. Compared to municipalities of the Northern Uplands, where many vineyards are exclusively old, the contrast is striking and illustrates the divergent development trajectories of the regions.

The *Hajós–Baja District* likewise presents a favorable picture. Most of its municipalities fall into the balanced (0.75–1.25) or moderate renewal (1.25–2) categories. Although some southern municipalities show low renewal, overall the district reflects stable structural renewal. It is noteworthy that strong renewal appears less frequently here than in the Csongrád District; however, the dominance of old plantations is also absent, indicating a balanced and sustainable development path.

The findings suggest that the districts of the Danube Wine Region are in a clearly more favorable position compared to areas such as Tokaj or Eger, where the index is zero or very low in many municipalities. While traditional, small-plot viticulture is aging in the northern and northeastern districts, the large-scale production systems of the Danube Wine Region have responded more flexibly to structural challenges.

In the *Balaton Uplands* and *Badacsony District,* low renewal is also observed in many municipalities. Here, viticulture—largely tied to tourism and small-scale production—has not been able to achieve the pace of renewal characteristic of the large estates in the Danube Region.

Based on the analysis of local autocorrelation of the Renewal Index, most vineyards in the Danube Wine Region did not show a significant spatial relationship with neighboring municipalities (grey category). In these areas, age structures are heterogeneous and vary by settlement, with no clear regional pattern emerging (Figure 6).

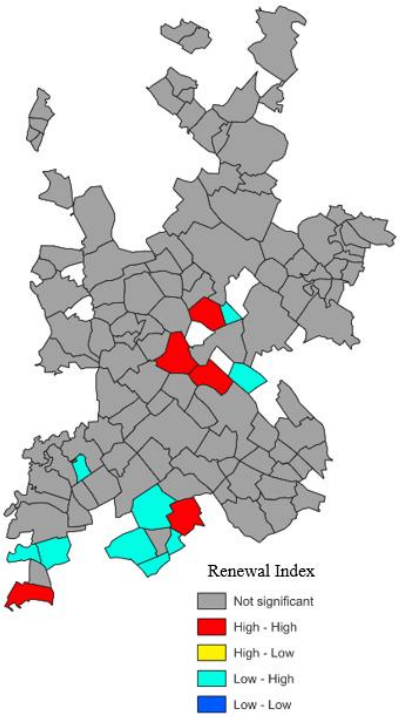

Figure 6 Spatial autocorrelation of the Renewal Index (Local Moran's I) at the municipal level of Danube Wine Region (2020)

Source: Vineyard registry data of the National Council of Wine Communities (HNT), 2020; author's own calculations and cartographic representation.

Nevertheless, in some municipalities and their surroundings, distinct cluster patterns can be identified. *High–High clusters (high renewal, high environment):* This category includes Jakabszállás, Bócsa, Szank, Tompa, and Dávod, where the proportion of young vineyards is outstanding and similar trends are also observed in their immediate surroundings. These municipalities can thus be interpreted as significant rejuvenation hotspots. *Low–High clusters (low renewal, high environment):* This group includes municipalities where renewal is low, but high values are typical in the immediate neighborhood. Such settlements include Fülöljakab, Jászszentlászló, Hajós, Mélykút, Bátmonostor, Vaskút, Bácsalmás, Csikéria, and Kunbaja. These areas appear relatively lagging compared to their dynamically renewing neighbors.

Conclusions

Although the analysis relied primarily on statistical data, the observed spatial trends must also be interpreted in light of different viticultural strategies. In several traditional wine districts, producers intentionally preserve older vineyards due to the cultural and market value of native grape varieties or the importance of yield restriction in maintaining quality. These factors may explain why the pace of vineyard renewal varies markedly between regions.

International reviews indicate that vineyard renewal rates and adaptation capacity vary substantially across wine-producing countries, with Western European regions such as France and Spain demonstrating more structured long-term adaptation programs (van Leeuwen et al., 2019; van

Leeuwen et al., 2024). These findings highlight that maintaining vineyard sustainability increasingly depends on the capacity to integrate climate adaptation into regional viticultural strategies.

The Danube Wine Region was given special emphasis in this research because it represents the largest contiguous vineyard area in Hungary, characterized by large-scale production structures and the most dynamic replanting activity in recent decades. This region therefore provides a benchmark for understanding how structural renewal can support the long-term sustainability of national viticulture.

The results confirm that Hungarian vineyards as a whole display an aging trend. The low proportion of young plantations poses a risk to long-term sustainability in many wine districts, particularly in historic regions where old vineyards dominate.The spatial patterns clearly show that rejuvenation is uneven: while the Danube Wine Region exhibits dynamic renewal processes, the risk of aging is pronounced in the Northern Uplands and several Balaton districts. This duality indicates that wine districts are following different development trajectories, shaped not only by economic and social factors but also by terroir characteristics and cultivation strategies.

The local autocorrelation analysis (Local Moran's I) revealed that rejuvenation hotspots are concentrated mainly in the Southern Great Plain, while the absence of renewal is more typical of northern areas. This underlines the need for differentiated support and development interventions: lagging wine districts require targeted incentives for rejuvenation, whereas dynamically renewing areas should prioritize the promotion of quality and sustainable production.

The Danube Wine Region is characterized by relatively young vineyards, which provide a favorable starting point for long-term sustainability. However, compared to other regions of the country, quantitative production dominates here; rejuvenation is therefore linked more to large-scale plantings than to small-plot quality viticulture.

The findings reveal significant differences in the age structure of vineyards across Hungarian wine districts. Whereas the Danube Wine Region contains a higher proportion of young vineyards, many historic wine districts are characterized by aging stocks. This divergence may determine future competitiveness and the sustainability of viticulture.

The spatial pattern of renewal is concentrated in the Danube Wine Region. Key hotspots include Jakabszállás, Bócsa, Szank, Tompa, and Dávod, while municipalities such as Fülöljakab, Jászszentlászló, and Hajós appear as lagging. From a policy and development perspective, this indicates that rejuvenation processes must be interpreted at the regional level, with attention also given to integrating lagging municipalities. As emphasized by Juhász and Győri (2024), the sustainability of local development initiatives is crucial for long-term regional competitiveness.

This research highlights that the age structure of vineyards is a key factor shaping the future of Hungarian viticulture. Successful examples of rejuvenation demonstrate that under appropriate economic and policy conditions, sustainable renewal of viticulture is achievable and can secure the long-term competitiveness of wine districts.

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