Wichmann

JoDLA

Journal of Digital Landscape Architecture

9-2024

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Erich Buhmann
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Statement of Purpose
The Journal of Digital Landscape Architecture addresses all aspects of digital technologies, applications, information, and knowledge pertaining to landscape architecture research, education, practice, and related fields. The journal publishes original papers in English that address theoretical and practical issues, innovative developments, methods, applications, findings, and case studies that are drawn primarily from work presented at the annual international Digital Landscape Architecture conference. Its intent is to encourage the broad dissemination of these ideas, innovations, and practices. Proposals for guest editors, topics, and contributions for special issues are welcome. The Journal of Digital Landscape Architecture is listed in the international citation database Scopus and in the DOAJ (Directory of Open Access Journals).

Cover Picture
The image presents a mixed presentation created by three different capture methods: 1) airborne laserscanning for the background, 2) a mobile laserscan from a car for the streetspace (City of Zurich, GeoZ), 3) a further mobile handheld laserscan by Leica for the underground channel. Source: Matthias Vollmer, ETH Zurich / MV Data: Swisstopo, City of Zurich/GeoZ, MV (Doctoral thesis: "Matthias Vollmer: The Depth of Landscape. Investigations into Point Cloud Modeling of the Zurich Subsurface", ETH Zurich, 2023).

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Preface

Since its beginnings at Anhalt University of Applied Sciences in 1999, the Digital Landscape Architecture Conference has traversed various cities such as Istanbul, Malta, Zurich, Munich, Boston, Bernburg, Dessau and Köthen, showing a pattern of geographical, institutional and methodological diversity. In 2024, the 25th DLA conference will be hosted by the TU Wien in Austria with a thematic focus on "New Trajectories in Computational Urban Landscapes and Ecology".

As our world experiences escalating interconnectivity and digital evolution, this conference aims to unveil transformative shifts in our approaches to urban landscapes and ecosystems, exploring the fusion of advanced computational techniques with socio-ecological principles. The aim is to foster innovative discussions that contribute to the evolution of various fields, such as landscape architecture, urban planning, architecture, and ecology, thereby offering insights into potential advancements and collaborations that shape more sustainable and livable urban environments. Central to the conference theme is the exploration of the dynamic interplay between advanced computational techniques, data-driven and co-creative design, and the intricate dynamics of urban ecosystems. In this way, the conference endeavors to provide novel insights and methodologies that align technological innovation with the intricate needs of the natural environment.

A total of 98 papers were selected through a thorough double-blind peer review process conducted by the founder and Scientific Director of DLA, Prof. Erich Buhmann and his editorial team.

In response to the current crises on our planet, there is a compelling need to focus on redesigning urbanization processes in line with socio-ecological goals. At the conference, we aim to ignite a crucial dialogue on these issues, bringing together authors of the papers and experts such as Prof. Bradley Cantrell (University of Virginia), Prof. Dr. Pia Fricker (Aalto University), Prof. Dr. Gerhard Schmitt (ETH Zurich), Associate Professor Dr. Defne Sunguroğlu Hensel (Southeast University), Viktoria Sandor (AIT Austrian Institute of Technology) and Fabian Pitscheider (Optimuse).

Our team, led by Prof. Dr. Susann Ahn, Prof. Dr. Thomas E. Hauck, Prof. Dr. Michael U. Hensel, Dr. Boris Salak, and Stefanie Tischberger, is excitedly preparing to welcome you to the conference. With our theme for this year, we aim to ignite active participation as we collectively forge new pathways towards a future where cities not only serve as hubs of innovation, but also stand as stewards of ecological vitality.

Vienna, March 15, 2024

Prof. Dr. Michael U. Hensel, Prof. Dr. Susann Ahn, Prof. Dr. Thomas E. Hauck,
Dr. Boris Salak and Stefanie Tischberger

TU Wien, Faculty for Architecture and Planning
Research Unit of Digital Architecture and Planning
Research Unit of Landscape Architecture and Landscape Planning

Foreword

This year marks the 25th Digital Landscape Architecture conference. Happy silver anniversary DLA!

The theme of my first DLA conference was Virtuality in Landscape Architecture. It was 2001 and I was asked to give a keynote about how landscape architects were changing from analog to digital methods as the 20th century was coming to an end. Most of the presentations discussed visualization technology – many discussed 3D visualizations. PAAR introduced us to the idea of using a gaming engine for landscape visualization. There was interest in "immersive" environments using multiple synchronized projections. Several presentations were about new software. It was all very exciting! In 2002 the theme was expanded to include GIS applications to which presenters enthusiastically responded. Participation was added to the theme in 2003, though the contributions focused on the technology and less on the quality of the participation. I may have been asleep, but it seems to me that we have proceeded largely along these lines for 20 years with interesting new contributions, but no major innovations that would change the nature of landscape architecture as much as moving from analog to digital methods did.

The prediction of revolutionary change has been on the horizon for what seems decades – computers would be able to make meaningful design decisions and designers would interact constructively with the public in real-time fully immersive virtual landscapes. I am excited to find that there are 2024 DLA presentations that do just that and go beyond the concept to provide evaluations of artificial intelligence (AI) in design and using immersive technology in co-design projects.

The importance of artificial intelligence was recognized by several JoDLA 5-2020 papers, but as TEBYANIAN characterized it "while [machine learning] generated landscape design solutions are possible, they rarely have been studied and remain a future field of research." In JoDLA 7-2022, ZENG & PENG presented a bibliometric analysis of digital landscape publications identified through the Web of Science and the JoDLA between 2010 and 2021. They recognized AI as falling within digital technologies, but did not identify it as a researched area. Two articles employed AI technology, one concerned recording human behavior for post-occupancy evaluation, and the other explores prototypes of human-plant-digital interactions. JoDLA 8-2023 included four AI related papers. An autonomous robot that cares for an urban garden, for instance while you attend the DLA. A second compared visualization created using traditional Photoshop collaging with text-based and sketch-based AI image generation. Twelve landscape architects and urban designers evaluated the visualizations and answered questions about the potential and implications of AI for landscape architectural practice. The third paper compared the usefulness of three AI image generators for producing 2D assets for inclusion in design renderings. The final paper identifies micro-level landscape qualities associated with Starbucks coffee shops in Hong Kong by using machine learning to interpret customer comments and relate them to visual features extracted from street photographs.

This brings us to JoDLA 9-2024. I would note that AI was not identified as a sub-theme for the 2024 DLA conference, yet over a dozen papers across seven sub-themes focus on AI!

Perhaps that is how it should be – less focus on the technology and more focus on the problems it can usefully address.

The AI papers are moving beyond giving AI a tryout to systematically evaluating its capabilities. GEORGE et al. prepared 15 prompts for "various ecological, stylistic, functional and aesthetic themes" to identify 20 appropriate perennials. Three tester submitted each prompt ten times to two versions of ChatGPT and the resulting plant lists were evaluated for accuracy, variety and distribution. Among the interesting results was a bias toward certain plants, even across the diverse criteria. The authors consider how such bias might affect plant selection. SENEM et al. created a custom database of garden plans evaluated for a number of attributes by a large number of people to train a deep learning AI. The AI was used to generate 100 garden plans which were then evaluated for graphic language, plan readability, building mass, land-use patterns, circulation, softscape pattern, diversity, and readability. TAN et al. provide another example of how AI can become a "collaborative partner" in creating form, in this case by providing real-time feedback about wind-related conditions. The role of AI as instructor was also explored by a couple of papers. Finally, I would like to draw attention to FERNBERG & ZHANG's paper characterizing five ways landscape architects relate to AI – a sort of Myers-Briggs for AI personalities.

The second subtheme that drew may attention this year was Co-creation, or approaches to participation. The predictions that public engagement will move into the virtual landscape are decades old. I am very excited by the paper from DHAINI & DREKSLER that compared two workshops with participants representing diverse interested parties. Their purpose was to design a pond area in a Bioreserve using a physical model and immersive VR (i. e., participant wore Oculus Quest 2 VR headsets and worked using Gravity Sketch 3D design software). A systematic evaluate was conducted through a questionnaire documenting their experiences. We need many more such comparisons to better understand how to effectively employ VR as a co-creation tool. Digital approaches to more traditional public participation methods were also discussed. For instance, POLYZOU & SECHIDIS adapted an opensource children's art program to overcome inhibitions in graphic expression. In addition to basic drawing tools, the program included a library of design-appropriate landscape features. Creating this image library was part of the co-creation process. A couple of papers also considered AI as a co-creation partner, for instance the paper by TAN et al. discussed above. I am looking forward to further development of this subtheme next year when the overall conference theme will be Collaboration.

Overall, I declare this year's Journal of Digital Landscape Architecture a successful representation of the diversity of activity in the field. I look forward to the stimulating discussions we are sure to have at the conference.

Prof. Dr. James F. Palmer, DLA Editor
Burlington, Vermont

Introduction

We are pleased to present to you the ninth issue of the Journal of Digital Landscape Architecture JoDLA 9-2024 with a total of 98 contributions. Approximately 150 authors from thirty countries sent in extended abstracts by the deadline in November. Thanks to the JoDLA review committee with more than eighty colleagues from twenty countries, we could select the final papers after two blind-review phases. These papers cover many of the topics of current digital landscape architecture. The contributions came from all Landscape Architecture programs in German speaking countries, and from a great number of American as well as Asian and Australian programs. Research units, and vendors specializing in applications for landscape architecture and leading landscape architecture offices also contributed. We are very happy that "publishing in JoDLA is an unwritten expectation – practically a requirement – for recognition / success in some university departments " and we will do our best to keep and develop this standard.

After being listed in Scopus, the journal is now also listed in DOAJ (Directory of Open Access Journals). Wichmann publisher has been making the JoDLA, and its forerunner publication Digital Landscape Architecture, accessible as open access papers since 2013, and therefore provides ten years' documentation of research in the area of Digital Landscape Architecture.

The cover of this issue, provided by Vollmer, Matthias, ETH Zurich, shows a mixed presentation using three different capture methods: an airborne Laser scanning for the background, a mobile laser scan from a car for the street scape, and a mobile handheld laser scan by Leica for the underground channel. The image indicates the multiple disciplinary cooperation among GIS and imaging experts in capturing and processing geodata, and the interdisciplinary application of this data by civil engineers, city planners and landscape architects as well. Digital landscape driven by multiple disciplines is the basis for the complex environmental modelling we are in need of.

The DLA 2024 is being organized for the first time by the Vienna University of Technology. We thank Univ. Prof. Michael U. Hensel PhD, Univ. Prof. Dr. sc. Susann Ahn, Univ. Prof. Dr.-Ing. Thomas E. Hauck for taking on the Chairs for DLA 2024. Being invited to Vienna also gave us the chance to thank Prof. Dr. Andreas Muhar from BOKU University of Natural Resources and Life Sciences for his early publication on digital landscape architecture in 1992. We would also like to thank Prof. Dr. Richard Stiles, the former landscape architecture chair of the Vienna University of Technology, for establishing the European Network of Landscape Architecture Educators, LENOTRE, instrumental in building our European community.

The main theme of DLA 2024 at Vienna University of Technology is **New Trajectories in Computational Urban Landscapes and Ecology**.

In addition to the main theme, we provided a number of other possible areas for submitting papers on current research or outstanding practice in digital landscape architecture.

The ninth issue of the Journal of Digital Landscape Architecture 9-2024 covers 98 contributions on the following current areas of research and prototype applications in digital landscape architecture:

- Digital Approaches to Participation and Co-creation
- Digital Responses to Nature-based and Nature-integrated Solutions
- Data-driven Design for Integrating Ecology and Architecture
- Ecological Modeling and Simulation
- Energy Landscapes
- Decision Support for Social-Ecological Systems
- Sensorics and Responsive Landscapes
- Resilient Landscapes, Global Change and Hazard Response
- UAV Imagery and Remote Sensing
- Geodesign Approaches, Technologies, and Case Studies
- Algorithmic Design and Analysis of Landscapes
- Landscape and Building Information Modeling (LIM + BIM)
- Visualization, Animation and Mixed Reality (VR, AR)
- Teaching Digital Landscape Architecture

In the preface, James Palmer gives an editorial overview of these many contributions.

We hope you will appreciate the ninth edition. The printed copies will be sent out on request to all participants before the conference at the beginning of June 2024.

You will find all the contributions online as open access publications at the gis.Point and gis.Open platforms of Wichmann http://gispoint.de/jodla.html.

We would also like to invite you to the next DLA conference. The 26th international conference on information technology in landscape architecture, Digital Landscape Architecture DLA 2025 with the main theme “Collaboration”, will be held from June 4 to 6, 2025 at Anhalt University in Dessau, Germany. Furthermore, we can already announce that the DLA 2026 will be hosted by University College Dublin.

The Journal of Digital Landscape Architecture invites you to submit ideas for special issues and topics. Please follow our continuously updated announcements and call for papers and posters at www.dla-conference.com. Here you will also find the complete online documentation of the DLA beginning from the year 2013. For earlier contributions of DLA publications, you may ask our JoDLA office.

Erich Buhmann, Stephen Ervin, Pia Fricker, Sigrid Hehl-Lange, James Palmer, as well as Michael U. Hensel, Susann Ahn and Thomas E. Hauck

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Wine Cultural Landscape's Adaptation: A Methodological Framework for the Dynamic Conservation of Cultural Heritage

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Abstract: Cultural landscapes, resulting from a long history of interaction between people and nature, are a well-recognized resource for improving the quality of life and promoting sustainable economic chains. However, the current climate change process, putting the fragile equilibrium between the natural and human environment at risk, represents one of the most significant threats to their conservation. In particular, due to their dependence on specific combinations of cultural and environmental factors, wine cultural landscapes require effective strategies to safeguard their tangible and intangible components. In this context, the research aims to provide decision-makers with a methodological framework for exploiting the potential of geospatial data in evaluating the adaptability of wine cultural landscapes to the environmental transformation produced by climate change. Moving from the existing policies and the most common indicators for landscape assessment in the European framework, the research proposes a data-driven workflow to evaluate the transformation of Wine Cultural Landscapes to support the activation of dynamic conservation strategies (ICOMOS 2017). The paper considers, as applicative case studies, two European Wine Cultural Landscapes through a comparative approach: the Rioja (Spain), included in the UNESCO candidate list, and the Colli Tortonesi (Italy), an Italian Protected Origin Denomination wine production area.

Keywords: Cultural landscape, climate change, wine, data-driven processes, multi-criteria analysis

1 Introduction

Cultural Heritage (CH), as a concept to identify items with recognized Outstanding Universal Values (OUVs), appeared in the international debate in dichotomic juxtaposition with Natural Heritage (NH), distinguishing the "work[s] of man" (UNESCO 1972) from geological/physical formations, specific habitats of animal species, etc.

However, soon, this separation appeared too restrictive and dependent on a Western cultural framework, opening the road for a hybridization that emphasizes the link between human beings and their environment. In this sense, the revision of the World Heritage Convention (WHC) introduced the concept of Cultural Landscape (CL) as the result of the combined work of nature and man (UNESCO 1992).

This extension of CH to CLs has been a result of a broader debate, fostered to shift the attention from CH as a valuable, isolated object to its interrelation with the context (UNESCO 1972, 2003, 2005): a living system (UNESCO 2005), inclusive of intangible components and the active action of people (UNESCO 2005 & 2012).

The concept of CL initially prevails on the 'rural landscape' one (CAMERON &RÖSSLER 2013), present from the 1980s in UNESCO's documents (SCAZZOSI 2018) with a similar purpose: to include in the protection mechanism activated by the World Heritage List (WHL) properties with both natural and cultural OUVs.

However, in time, the meaning and role of Rural Landscape (RL) have been specified as a subcategory of CLs: one of the most common types of 'continuing cultural landscapes', co-produced by human-nature interaction for the production of food and another renewable natural resource (ICOMOS 2017).

In defining RLs as complex systems of different kinds of valuable elements (both physical and intangible), ICOMOS underlines their continuous, irreversible, and inevitable processes of transformation (ICOMOS 2017), introducing the concept of 'dynamic conservation' as a best practice to safeguard the heritage values respecting the intrinsic RL's dynamism.

In Europe, despite the immense scale of socio-economic changes that have accompanied industrialization and urbanization in many parts of the continent (EEA 1995), RLs represent 95% of the territory (AGNOLETTI 2014). Due to their historical interconnection with European cultural development in several countries, they have a quantitative and qualitative relevance that paradoxically has to face the current and foreseen urbanization trends. About 28% of the EU population lives mainly in inner peripheries and rural areas, 31.6% live in small and suburban areas (intermediate areas), and the remaining 40.4 are concentrated in larger cities (Eurostat, 2017). Across the world, the trend towards urbanization seems unstoppable. Forecasts indicate that by 2050, city dwellers will increase by 24.1 million, while the population of mainly rural areas will decrease by 7.9 million (OECD 2016). In the following decades, depopulation will affect the internal European areas of Spain, France, Germany, Poland, Slovenia, Romania, Czech Republic, Greece and Italy (VERBURG et al. 2010), following two different modalities: the first caused by the emigration of a class demographic in working age towards the big cities, the second connected with the progressive ageing of the population of the places. A low birth rate generally accompanies this phenomenon by a low birth rate (GOLINI et al. 2000).

Consequently, the depopulation, land abandonment, and urban expansion (and the related infrastructure) threaten the conservation of the significant or characteristic features of RLs due to an acceleration of their transformation promoted by the European Landscape Convention (EU 2000).

Furthermore, the system of processes defined by the umbrella term of Climate Change (CC) substantially impacts the conservation of RLs as living systems of cultural and natural elements. If, by definition, the climate is a temporal stability of environmental conditions, its sudden variation deeply affects the long-lasting interaction between human presence/action and its environmental context.

In the update of the "Policy Document on Climate Action for World Heritage" (UNESCO 2021), the member states identify CC as one of the most significant threats to CH and define guidelines and specific goals for activating urgent preservation strategies.

The document also recognizes CLs as places that might significantly contribute to climate mitigation, providing land use management solutions and traditional knowledge with a solid and harmonious human connection to the natural environment.

Thus, CLs represent something to preserve and a driver for activating adaptation strategies to face the environmental changes generated by CC.

From the Cork Declarations (EU 1996 & 2016) to the EU's Common Agricultural Policy (CAP) and the specific long-term vision for EU's Rural Areas (European Commission 2022), the exploitation of rural potential as a driver of sustainable development and as a vector of mitigation and adaptation strategies to face CC stands at the core of several European policies for rural areas, targeted at encouraging their economic development, promoting counteraction against depopulation, ageing and land abandonment trends. The main pillars of this action are economic diversification, digitalization (both in terms of education and infrastructure) and the activation of job creation and positive generation renewal trends.

However, the enhancement of rurality as a driver of sustainable socio-economic development overlaps and, sometimes, interferes with the policies more related explicitly to landscape preservation, at the point that, even though the debate has been in progress for years, a specific European agreement about the protection of RLs is still to be defined (EMA 1995).

Some attempts have been made to develop indicators to identify and classify RLs for monitoring the integration of environmental concerns into European policies (PARACCHINI & CAPITANI 2011, UNGARO et al. 2014, MEDEIROS et al. 2021, SABBIONI 2006). The growing availability of spatial data at high spatial and temporal resolution encourages the development of data-driven approaches to landscape monitoring, providing adequate and flexible methods and tools to support decision-making processes, helping in defining what to be preserved in RLs through a multidimensional measurement of their status and their transformation.

This possibility becomes fundamental in the perspective of dynamic conservation of RLs in the context of CC, where the environmental transformation threatens the existing landscapes but generates new potential landscapes (MYGA-PIĄTEK & RAHMONOV 2018).

The core of this research is evaluating the current RLs' status and their adaptation to new environmental contexts, aiming to provide a methodological framework based on geospatial analysis to support the development of dynamic conservation strategies.

The integration of digital technologies, both as tools and methods, offers the opportunity to exploit the potential of the growing availability of spatial data to turn the RL's complexity into a computable object, supporting the monitoring of its condition and transformation, along with the simulation of future scenarios.

2 Methodology

The research focuses on wine cultural landscapes (WCLs), a specific kind of RL produced by developing viticulture traditions. Currently, the WHL includes fourteen properties related to winemaking (PIJET-MIGON & MIGON 2021), among which eight are classified as CLs, almost all in Europe.

Winemaking is a traditional practice and a leading economic sector in several European countries; however, WCLs are particularly vulnerable to CC due to their high dependence on climatic and environmental conditions (CARROQUINO et al. 2020).

The soil erosion impacts the traditional shape of wine hills, while the water stress and temperature increase affects all the bio-cultural processes, from grapes maturation to wine quality and the seasonality of winemaking (IGLESIAS et al. 2010, JONES & ALVES 2012, FRAGA et al. 2016a, RAMOS 2017).

Thus, it becomes fundamental to simulate predictive scenarios of the environmental transformation to understand how WCLs will be affected and how conservation/adaptation strategies can reduce the loss of current WCLs, taking advantage of new suitable areas.

The proposed methodological framework is based on a data-driven approach, focused on using the available geospatial repositories for a multidimensional measurement of RLs, both in a descriptive and predictive perspective.

The composite nature of RLs has required a preliminary selection of indicators based on the existing literature on landscape modelling at the European and national levels (EUROSTAT 2010, PARACCHINI & CAPITANI 2011, ISTAT 2021, AGNOLETTI 2019, BATTISTI et al. 2022).

Three main dimensions have been identified: i) ecology, to qualify the geophysical structure of RLs, its diversity and the equilibrium of human presence and activity with the natural environment; ii) culture, focused on the social awareness of the RL's relevancy for the community; iii) dynamicity, considering the current, past and forthcoming transformation processes.

These dimensions have been analyzed through three indicators (Tab. 1), including quantitative and qualitative parameters. The indicators are intended as an open measurement tool to activate the workflow, providing the model to structure the initial input. However, during the expected iteration of the process, they should be integrated, engaging the stakeholders involved in the RL's management (public administration, private companies, associations, citizens, etc.).

The dimensions and indicators support both an analytic description and synthetic classification of RLs, providing the necessary information to understand the RL's behaviour about specific phenomena, supporting as such the definition of coherent adaptation/mitigation strategies and a synthetic classification of the RLs in terms of naturalness (ecology), perception (culture) and transformation (dynamicity), setting a comparative framework for the definition of differentiated policies, respectful of the heterogeneous nature of RLs.

Table 1: Dimensions and indicators for RL's analysis

Dimension	Indicator Code	Indicator
Ecology	E1	% surface rural landcover
	E2	rural entropy
	E3	degree of hemeroby
	E4	landscape units' diversity
	E5	orography
Culture	C1	% surface of protected areas
	C2	number of recognized valuable landscape elements
	C3	number of tourist attractions
Dynamicity	D1	depopulation
	D2	urbanization
	D3	% crop surface change
	D4	Normalized Difference Vegetation Index (NDVI) change
	D5	Leaf Area Index (LAI) change

In addition to the general indicators defined for the RLs' preliminary analysis, specific parameters have been selected for the WCLs to understand, according to the different dimensions, the relevancy of vineyard cultivations and winemaking practices (Tab. 2).

Table 2: Specific indicators for WCL's analysis

Dimension	Indicator Code	Indicator
Ecology	EW1	% vineyards surface
	EW2	vineyards distribution
	EW3	grapes variety
	EW4	% surface for *vitis vinifera* cultivation
	EW5	number of trees/ha
	EW6	grapes production/ha
Culture	CW1	age of the vineyard cultivation
	CW2	number of PDO's farming activities
	CW3	number of trees/ha in PDO's farming activities
	CW4	grapes production/ha in PDO's farming activities
	CW5	number of tourist attractions related to winemaking
	CW6	number of tourist services (accommodations, restaurants) related to the vineyard's farming activities
Dynamicity	DW1	number of workers in winemaking farming activities (trend)
	DW2	population trend in vineyard areas
	DW3	% built-up surface change in vineyard areas
	DW4	% crop surface change in vineyard areas
	DW4	Normalized Difference Vegetation Index (NDVI) change in vineyards areas
	DW5	Leaf Area Index (LAI) change in vineyards areas

This model activates the workflow, articulated in four steps:

1) Identification of the RL: This is the initial, fundamental phase to define the object of the analysis spatially and conceptually. They can be used as a reference to the existing policies which provide a territorial base and a brief description of the protected area (e. g. UNESCO buffer and core zones, PDOs, etc.);
2) Data collection: selection of the data sources for populating the model. They can be considered repositories of spatial data at different scales, both international (to allow the comparison between different countries) and national or sub-national (to work on a higher level of detail), giving priority to i) comparable datasets, ii) higher resolution and iii) update. The selected sources have to be harvested through an Extraction/Transformation/Load (ETL) process, starting from the definition of query parameters (spatial and temporal range, variables, etc.), proceeding to a normalization of the datasets (reprojection, data cleaning, downscaling, etc.) to achieve an integrated spatial database where to store and update the collected data, making them available for the next step;
3) Analysis: elaborating the collected data, according to the model's dimensions and indicators, provides a parametric description of the area. This base of knowledge permits to characterize the RL, considering its structural elements and transformation dynamics.

This classification defines i) a comparative framework for identifying similarities and differences between RLs in different contexts, as such supporting ii) the development of specific adaptation/mitigation strategies targeted to clusters defined by recurrent configurational patterns;

4) Simulation: the outcomes of the third analytic phase define the present status of the RL, along with its current and past transformation dynamics. In the fourth phase, in terms of suitability, this system is evaluated by simulating transformation scenarios. Changing some parameters in the RL's natural and human environment generates a virtual context where the possibility of the existence of the RL, as it is or in a different configuration, can be tested. This phase provides, as output, a visualization of i) the RL's elements that are suitable to survive in the simulated scenario, ii) the features that are most vulnerable to the transformation dynamics and require adaptation strategies, iii) areas that are currently peripheral in the RL's system, but that, in the new environmental conditions, are suitable for the generation of a potential RL.

The workflow is intended as an iterative process to guide decision-making through identifying the main components of RLs and their transformation trends, visualizing the simulated scenarios and discussing the outcomes with the stakeholders in participatory activities. This iteration is fundamental for collecting new inputs, data and parameters to integrate the model with more granular information or specific indicators. In this way, it is possible to evaluate different strategies in an open process fostered at supporting *ad hoc* safeguarding strategies, that working on specific components through targeted actions could encourage dynamic conservation of RLs.

The paper proposes a comparative application of this workflow, from the data collection to the simulation, to two European WCLs identified by a similar system of protection (the wine PDOs) but diverse in their characteristics and included in different protection systems.

3 Case Studies

3.1 Comparison Framework Overview

The two selected case studies are the Rioja (Spain) and the Colli Tortonesi (Italy), defined by the discipline of a European and nationally recognized wine PDO. The comparison aims to understand if and how the protection policy of a registered excellent product impacts the conservation of the landscape in the same international framework but in different national and local systems of policies.

The methodological framework developed by the research aims to provide a system of measurement that, parametrizing the WCL, helps identify differences and similarities between the two cases, supporting the definition of standard best practices along with specific actions.

The four workflow steps have been developed for the two cases, moving from a similar identification of the territorial base, determined by the definition provided by the PDOs' documents, and considering the conservation policies at different levels.

The two areas differ in qualitative and qualitative terms, considering the extension, the population and the normative centrality as protected areas. The Rioja is broader, more populated and included in the UNESCO WHL's tentative list (properties which the UNESCO members consider as cultural and/or natural heritage and therefore suitable for inscription on the WHL, UNESCO 2020), while the Colli Tortonesi is in a low-density rural area, at the outskirts of the more famous “Wine Cultural Landscapes of Langhe, Roero and Monferrato”, recently included (2014) in the UNESCO WHL.

However, among the rejection reasons for Rioja's application to WHL is the fragmentation of the WCL in some of its areas, a structural characteristic also documented in the description of landscape units in the Colli Tortonesi area (Regional Landscape Plan of Piedmont Region 2017). Furthermore, the Colli Tortonesi will receive a new centrality, with potential opportunities and threats, by activating the European connection between Genova and Hamburg (via Milan).

In the data collection phase, moving from the above-listed indicators, data sources have been selected and integrated at the European, national, and local levels to support the comparative framework while maintaining the level of detail provided by regional repositories (Tab. 3).

Table 3: Selected data sources for the two case studies

Indicator Codes	Data Source
E1, E2, EW1, EW2	elaboration from CLC 2018
E3	reclassification of CLC 2018 (PARACCHINI & CAPITANI 2011)
E4	Regional Landscape Plan of Piedmont Region 2017 (Colli Tortonesi), Rioja Province 2011 (Rioja)
E5	elaboration from 10m DEM (Piedmont Region 2011) and 5m DEM (CNIG 2008)
C1	European Natura 2000
C2	Regional Landscape Plan of Piedmont Region 2017, Rioja Province 2011
C3, CW5, CW6	Tripadvisor
D1, DW2	Global Human Footprint (GHF)
D2, DW3	Copernicus Land Cover Built-up Fraction (BF 2015-2019)
D3, DW4	Copernicus Land Cover Crop Fraction (CF 2015-2019)
D4, DW5	elaboration from Sentinel-3 OLCI (2020-2023)
D5, DW6	elaboration from Sentinel-3 OLCI (2020-2023)
EW3, EW5, EW6, CW1, CW2, CW3, CW4	Regional Agricultural Cadaster (Piedmont), Rioja PDO
EW4	elaboration from 10m DEM (Piedmont Region 2011) and 5m DEM (CNIG 2008)
DW1	Italian National Institute of Statistics (2015-2019), Instituto Nacional de Estadistica (INE)

Integrating different sources has been fundamental to achieving an adequate spatial resolution for a comparative territorial analysis of the two selected areas. However, this heterogeneity has implied a normalization of different spatial resolutions: 1kmx1km (GHF), 100mx100m (CLC), 10mx10m (Piedmont DEM) and 5mx5m (CNIG DEM).

Furthermore, the simulation scenarios have been considered the main climatic indicators published by the European COordinated Regional Climate Downscaling EXperiment (EURO-CORDEX) and collected through the Copernicus Climate Change Service (C3S) API

(COPERNICUS CLIMATE CHANGE SERVICE 2019). This dataset has a spatial resolution of 0.11°x0.11° (approximately 10kmx10km).

In the normalization process, the EURO-CORDEX and GHF datasets have been downscaled to a 100mx100m resolution, maintaining the value per cell of the first and distributing the population value of the second. At the same time, the DEM has been upscaled, considering an average value per cell.

For the suitability analysis of WCL, the Representative Concentration Pathway (RCP) scenarios 2.6 and 8.5 at 2050 have been considered, calculated through the CNRM-CERFACS-CM5 model, considering, as variables, the air temperature (maximum, minimum and average), relative humidity and mean precipitation. These indicators have been integrated into the calculation of the Huglin Index, Winkler index, growing season temperature (BAI et al. 2022), dryness index and hydrothermic index (SGUBIN et al. 2022) as well as recognized dimensions for measuring the climatic suitability to the development of the grapevine's phenological phases. However, the WCL stands on more than just the environmental possibility for the *Vitis vinifera* to grow; it also requires the consideration of anthropic trends (D1, D2, D3) and adequate vegetation status (D4 and D5). These variables have been integrated into the simulation model as risk indicators.

The integration has been realized in two steps: firstly, it has been composed of the suitability index (SGUBIN et al. 2022), and then it has been multiplied by a composite index calculated through the normalization of D1 – D5 through the information entropy weighting method (SHANNON 1948). In this way, the future scenario generated by climatic projections, which defines the potential suitability for WCL, is adjusted by positive and negative factors, which can support the preservation of WCL or contribute to determining its loss.

This model aims to set an open framework for activating the iterative process defined in the methodology, which can produce different simulations supporting the decision-making process by integrating new indicators.

3.2 La Rioja

The Rioja PDO's area is located in Northeastern Spain, crossed by the River Ebro, which generates two different physiographical sides (a system of reliefs and valleys on the West side and a network of tributaries on the East) and is protected (in the North) by the massif of the Sierra Cantabrica.

The Rioja includes 205 municipalities, distributed in the three autonomous communities of La Rioja, Navarra and the Basque Countries, with an overall population of around 315,000 inhabitants, half of which are located in the main centre of Logroño (150,020 in.) and other 80,000 distributed in the medium size municipalities of Calahorra, Arnedo, Haro, Lardero.

The territory has been used for vineyard cultivation since the pre-Roman age, generating, in time, traditional techniques related to winemaking and grapes growing.

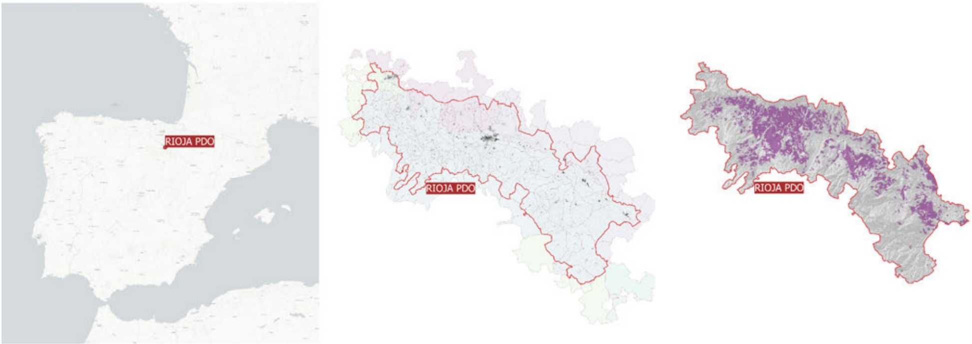

Fig. 1: a) Rioja is located in the North-East of Spain. b) It includes 205 municipalities, and it crosses the three autonomous regions of Navarra, La Rioja and the Basque Province of Alava; c) the vineyards cross the region from East to West, covering 42% of the total surface (CLC 2018) [Sources: Carto Positron Basemap, Open Street Map, CLC 2018, 5m DEM, maps elaborated by the authors].

3.2.1 Identification

Rioja is the most ancient PDO in Spain, dating back its origin to 1925 as a development of a previous, long history of promoting and protecting the local grapevine farming. The PDO first defined the production area as a territory, establishing an official regulation. Over time, the area progressively expanded, including new wine varieties. In 2017, the regulation included the geographical entity of the *viñeto singular* (singular vineyard): a territorial unit smaller than the municipality, with specific agrogeologic and climatologic characteristics that distinguish it from the surroundings.

The EU PDO's register included Rioja since 1986; since 2013, it has been a candidate as a WH site. One of the main reasons ICOMOS rejected the candidacy was territorial delimitation due to its fragmentation (UNESCO 2015, ICOMOS 2015).

Over the last 10-20 years, Rioja winemaking has added wine tourism as a new product. Among other activities visitors will carry out are visits and excursions through the vineyards, and their attractiveness is growing. The vineyard's landscape, aesthetic and cultural value have led the Government of La Rioja to consider the vineyard as a Landscape of Cultural Interest. However, some shadows arise after the landscape changes of the last decades, as the growing trend towards homogenization, defragmentation, expansion of espalier plantations, and migration of hillside vineyards towards flat and more fertile areas threatens to transform a unique, cultural and beautiful landscape into a very general landscape, similar to other European vineyard landscapes. The environmental conditions and the tillage of generations of farmers gave rise to a diverse landscape, rich in biodiversity and aesthetics, unique and singular; a landscape that has evolved towards the homogenization imposed by mechanization and uniform European Union legislation, which constitutes a threat to the maintenance of the cultural landscape of the vineyard.

All this is combined with the need for more agreement for the historical management of the Rioja PDO territories due to the difference in criteria between the Autonomous Communities of La Rioja and the Basque Country.

3.2.2 Analysis and Simulations

Fig. 2: a) the hemeroby index qualifies the area considering the spectrum between the major (in red) and minor (in blue) impact of human presence/activity on the natural environment. b) the distribution of the built environment as a fraction of the cell surface let emerge the presence of architectural/infrastructure elements in the predominantly natural context. c) the map shows the higher changes (in red) in the built fraction between 2015-2019.

The analytic phase characterizes Rioja's territory as predominantly rural, with 42.2% agricultural land cover (E1) and 15% vineyards (EW1). The average hemeroby index (E3) of 3.73 stands between the semi-natural (mesohemerobe) and relatively far from natural (β-euhemerobe) classes, revealing the impact of rural activity on the modification of the natural environment (Fig. 2a). The rural structure presents an average entropy index (E2) of 0.63, lowered by the predominance of vineyards (65% of rural landcover surface). The built environment follows a hierarchical network distribution, with higher-density urban areas and small villages dispersed in the rural environment (Fig. 2b). The depopulation trend in the last five years (D1) shows a cluster in the Northwest area (municipality of Miranda de Ebro), which is out of the central vineyards cluster and, more generally, this demographic phenomenon affects less the territories directly including vineyards landcover. The Rioja PDO recognizes 570 vineyard farming activities (CW2), around half of which (210) provide tourist services and 360 providers of specific ecotourism experiences (CW5, CW6). The growth of the built environment in the last five years (DW3) affects more the southern part; however, close to the main centre of Logroño, there is an active urbanization process directly affecting the vineyards area (Fig. 2c).

The data-driven exploration has revealed a territory highly centred on the presence of vineyards, both from a quantitative and qualitative perspective: a rural element that characterizes the natural environment, with its historical presence, deeply connected with human activity. A dedicated protection system for high-quality winemaking has determined the growth of several economic activities in the sector, not only targeted to agricultural production but also to the activation of tourist services for enhancing the attractiveness of new economic chains. However, the urbanization trend and the transformation in the environmental condition can produce potentially dangerous dynamics for the WCL's conservation.

Fig. 3: The simulation has considered climate data projections in the a) less dangerous (RCP 2.6) and b) most dangerous scenarios, considering the relative variation in the suitable areas for vineyards cultivation (from yellow to blue), providing, for each scenario, c) visualization of the vineyards areas in danger (in magenta) and the new potentially suitable areas (in green).

The simulation phase aims to put the WCL in new environmental conditions, determined by CC in correlation with anthropic dynamics. The comparison between the minimum (RCP 2.6, fig 3a) and maximum (RCP 8.5, fig 3b) increase in temperature in the short period (2050) reveals how the spatial distribution of the suitability areas does not significantly change in the two simulations, while there is a quantitative contraction in the most extreme one, with a potentially significant loss of almost the 90% of the existing vineyards area, with the compensation of only the 0.1% of new suitable zones (Fig. 3c).

The simulations identify a central cluster with a stable suitability condition and a distributed longitudinal loss of these characteristics across the whole area, with small variations determined by orographic conditions like the presence of higher reliefs, which can potentially mitigate the temperature increase. The structural homogeneity of the territory does not play in favour of the generation, inside of the territorial unit defined by the PDO, of new potential suitable areas.

The structural characteristics of the WCL that emerged in the identification phase are fundamental to evaluating the simulation's resulting scenarios and developing specific preservation strategies. The suitability index calculated through the elaboration of climatic projections shows an asymmetric development of environmental conditions in the area, with a higher Winkler index in the Eastern and Western areas and lower values in the Centre and South. However, the demographic trend and the expansion of the built environment negatively impact the weighted index.

3.3 Colli tortonesi

Colli Tortonesi is an Italian PDO located in the Northwest of the country (in the Piedmont region), in a geographical area where the Plain of the Po gradually shifts into the Apennine Mountains through a system of hills and river valleys (Fig. 4). Since the first human settlements, the area has been strategically located at the crossway of the communication network (rivers, roads, railroads). Tortona, the main urban centre of the area, is a 25,000 inhabitants Roman age settlement situated in a strategic position for its centrality between the urban polarities of Turin, Genoa and Milan and its connection with the European TEN-T corridor n. 3, which aims at linking the North and the Mediterranean Sea.

Fig. 4: a) Colli Tortonesi is located in the Northwest of Italy. b) Its main urban centre is Tortona, and it includes 30 other municipalities with less than 5,000 inhabitants. c) The vineyards are concentrated in the Northwest, approximately 300-700 m above sea level.

On a local scale, Tortona works as a polarity for a network of around 30 villages (most under one thousand inhabitants) that populate the river valleys between the city and the Apennine Mountains.

3.3.1 Identification

The tradition of winemaking in Piedmont and the related landforms that characterize its RLs is rooted in the pre-Roman age, developing in connection with several aspects of the local culture. The PDO has been an active instrument of protection since 1974: it specifies the relationship between the wine and the production area, highlighting how the lithological characteristics of the ground generate the specific salinity of the wine.

In the regional policy framework, attention emerges to the RL's presence and relevancy in the area (e. g. the public interest recognized to the RL from Tortona to Novi Ligure), even if not explicitly targeted to WCLs. The Regional Landscape Plan (2017) divides the area into two landscape areas characterized by fragmented agricultural land use.

The Colli Tortonesi is also not included in the National Register of Historical Rural Landscapes (2012), which provides, at a national level, specific indicators for evaluating RLs in terms of landscape patterns, farming techniques, and architectural elements.

In 2014, the nearby WCLs of Langhe, Roero and Monferrato were included by UNESCO in the WHL, adding an international policy layer. Colli Tortonesi is not included in this property's core/buffer zone. However, as a side effect, in the last eight years, four vinaries *versanti* (hillsides) of this area have been awarded with a high-quality prize inscribed in the promotion strategies activated by the UNESCO recognition.

Compared to Rioja, Colli Tortonesi remains a marginal WCL, in terms of protection systems, at different levels, characterized by fragmentation that makes it incomparable with the most famous Italian and, in particular, Piedmontese wine production areas. However, this weak protection system makes the case study interesting for considering its transformation dynamics. Furthermore, the ongoing work for the activation of the European TEN-T corridor, empowering the accessibility of the area, will probably give a new attractiveness to the area, both in economic and tourist terms, generating opportunities and threats for the WCL.

3.3.2 Analysis and Simulations

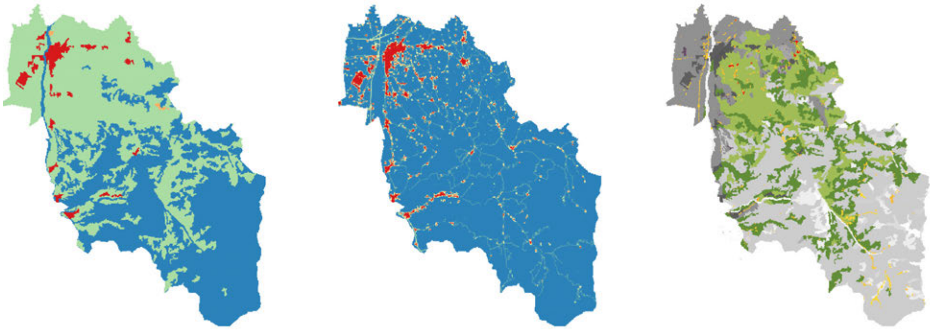

Fig. 5: According to a) the hemeroby index, the Colli Tortonesi is divided into three areas, with a decreasing degree of artificiality, from the plain to the inner mountains; however, b) the distribution of the built environment let emerge the presence of architectural/infrastructure elements also in the predominantly rural context; but c) the higher changes in the built environment (increase between 2015-2019) are concentrated in the nearby of the urban areas, affecting also the nearby vineyards.

The analysis of the Colli Tortonesi area revealed a predominantly rural environment, which occupies 45% of the total land cover surface (E1). However, only 2.5% is dedicated to vineyards (EW1), which are not explicitly classified in the land cover (CLC 2018). Integrating local data sources (regional land use map, regional agricultural cadastre), it has been possible to map the existing vineyards: the majority of them located in areas classified as complex cultivation patterns (CLC code 242) and land principally occupied by agriculture with significant areas of natural vegetation (CLC code 243), which are the predominant rural landcover (nearly 90% of the total), maintaining the rural entropy index in the average 0.58 (E2). The hemeroby index (E3) of 3.03 confirms the semi-natural quality of the area (Fig. 5a), where most of the total population is concentrated in the main urban/artificial environment of Tortona and the Western side, closer to the central axis of transportation network (railway and main roads). However, the spatial analysis of the built environment shows the capillary presence of small infrastructures and architectural elements even in the inner areas (Fig. 5b), particularly in the vineyards. The coexistence of natural and artificial elements in the Colli Tortonesi RL is well documented in the first documents of regional protection policies (1975), a significant part of its history. Thus, as the analysis of soil consumption trends (D2) has revealed, the growth of the built environment does not affect only the urban areas, generating also new constructions in the vineyards areas due to their closer location to the main urban areas (Fig. 5c).

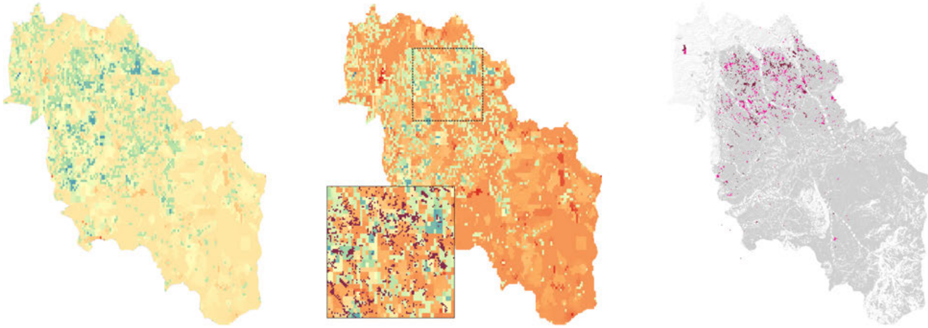

Fig. 6: The simulation of the a) low and b) maximum environmental transformation scenarios show how the suitability areas progressively decrease, generating c) new potentially usable lands for vineyard cultivation (in green)

The simulation phase has revealed how the physical heterogeneity of the Colli Tortonesi area works as a potential generator of new suitable conditions for vineyard cultivation.

Compared to the simulation scenarios for the Rioja, the potentially new suitable area (Fig. 3c) is relatively more extensive, representing 0.2% of the total PDO's surface. The RCP 2.6 (Fig. 6a) scenario reveals a substantial continuity between the current vineyards and the foreseen suitable areas, confirming their prevalent distribution in the North. The RCP 8.5 (Fig. 6b) shows a more fragmented configurational pattern, with a sensible endangerment of the current WCL. However, both the scenarios reveal a potential extension of the *vitis vinifera* cultivation in the inner area, where the elevation mitigates the temperature growth and the territory is currently less affected by the urbanization phenomenon.

This condition, from one side, opens the possibility for the WCL to persist, but not without a significant systemic transformation: the potential extension of cultivated areas in previously natural ones affects human-natural equilibrium (impacting indicators like E3); on the other side, the hybridization between rural and built environment, which characterizes the WCL in the area, is questioned by the new configurational pattern.

Furthermore, the specific characteristics of the protected wine, which highly depends on the salinity of the soil, could be affected by the characteristics of the suitable areas, requiring, in this sense, the integration of geological and pedological indicators.

In this sense, the effectiveness of the PDO, as a mechanism of protection generated by the development of a collective interest in high-quality products, is deeply connected to the environmental context and its transformation. While it is capable of activating the required cultural and economic interests, able to orient the WCL's generation and preservation, it also has to follow its dynamic transformation, including, in its policies, strategies to maintain a balance between the excellence of the production chain and the environmental change.

4 Conclusions

The comparison between two areas encompassed by a similar protection policy, targeted to define the production zone as a stable condition for the production of high-quality wine, has revealed how the configurational characteristics of the WCL impact the transformation scenarios, becoming, as such, significant information for developing safeguarding strategies. In particular, the Colli Tortonesi, less characterized as a WCL due to the fragmentation and diversity of its rural environment, is more adaptive to the forthcoming transformations, providing more possibilities for vineyards to develop in new areas. This first hypothesis has to be verified, including new, more detailed microclimatic and agrometeorological indicators, to understand if and how the environmental change affects the characteristic salinity of the Colli Tortonesi wine, dependent on specific geophysical properties of the site. On the other side, the WCL of Rioja, which is a predominant human/natural ecosystem of the area, having been and becoming a factor of economic development, stands on the fragile equilibrium determined by the combination of climatic and anthropic trends, requiring to develop conservation strategies balanced between the economic productivity of the area and its conservation as a rural landscape.

The further development of the proposed applications consists, from one side, of the iteration of the process, including the inputs received from the local stakeholders and automation of part of the workflow in a data infrastructure aimed at supporting the continuous update of the collected database, opening to the integration of real-time remote sensing and IoT data streams. This digital infrastructure aims to provide decision-makers with an operative tool that can simulate predictive scenarios to face the rapidity of current and future environmental changes.

However, the possibility of parametrizing the landscape as a measurable system of processes, encouraged by the growing opportunities offered by the continuous development of digital technologies, is highly dependent on and influenced by the definition of the analytic model.

In particular, for a workflow aimed at turning heterogeneous data into operative information for decision-makers, selecting the indicators and the visual outcomes must pay attention to their partiality. Thus, flexibility, in terms of integrating new parameters and regeneration of the simulated scenarios, is fundamental to avoid the risk of overlaying the future perspective with insufficient accurate projections, with a significant potential countereffect.

Furthermore, the required downscaling of predictive datasets to an adequate spatial resolution for analyzing the selected areas generates a methodological bias with a limitation in terms of the accuracy of the results, in particular when the scale of the analysis tries to move from a general overview of the PDO's territorial base to landscape units, clusters of vineyards or isolated ones. Even if the proposed methodology is not targeted to precision farming, maintaining a holistic perspective on RLs and their complexity, as in terms of mutliscalarity, the possibility to integrate predictive datasets with a higher spatial resolution, or to derive projections from time series of Earth Observations imageries, represents a line of development.

The possibility of quantifying, localizing and visualizing the balance between what is endangered by the ongoing transformation and potentially lost and what is potentially gained, in terms of suitable areas for imagining a WCL future development, opens the road for imagining and co-designing dynamic conservation strategies, where the landscape is safeguarded as a living system, potentially adaptable to different transformation scenarios.

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