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Special Issue 2.2025

Climate crisis and spatial planning

Green infrastructure and supply of ecosystem services

The climate crisis and its impacts are affecting, with ever greater pace and intensity, urban, peri-urban, and rural contexts, thus significantly impacting the environment, local development, and quality of life. Therefore, the identification and implementation of planning actions aimed at strengthening the resilience of spatial systems and at accelerating the ecological transition are highly desirable, mainly based on the effective and sustainable use of the functions of nature and natural resources.

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The cover image: The pedestrian route of Via Chiaia in the City of Naples by TeMA Editorial Staff

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Predicting the aesthetic impact of wind turbines and their influence on landscape value

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Abstract

The growing reliance on renewable energy sources (RES) is a direct response to global challenges such as climate change and the limited availability of fossil fuels. Due to their low costs and scale suitability applications, wind turbines and solar panels are among the most widely adopted RES technologies for electricity generation. Their benefits are generally considered to outweigh the disadvantages. However, despite their image as green alternatives these technologies face opposition due to concerns about noise, visual impact, and possible negative effects on ecosystem services. Following the EU Green Deal and its goal of achieving climate neutrality by 2050 the adoption of green energy technologies requiring immediate implementation beyond legislation. The Basilicata region in Italy is among the most affected areas having the highest percentage of wind farms and experiencing notable territorial fragmentation due to their installation. This study aims to assess not only the environmental impacts of wind turbines but also their social and aesthetic effects. Expert-based assessments and spatial analyses will be conducted followed by the Scenic Quality Model within InVEST to evaluate visual impacts. The findings provide valuable insights for policymakers, planners, and researchers involved in sustainable land management and renewable energy planning.

Keywords

InVEST model; Sustainable land management; Scenic quality; Renewable energy planning; Environmental assessment

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1. Introduction

Rising the global demand for energy, represents one of the most urgent and complex issues of the 21st century (Codemo et al., 2021). While, to address climate change, we need to reduce our reliance on fossil fuels. One of the direct solutions that proposed to us is to increase the use of renewable energy sources (RES), such as wind and solar energy (Bhatti et al., 2024; International Energy Agency, 2023) The use of RES, especially in European countries, intensified in November 2019 when the European Parliament adopted a plan known as the Green Deal. This plan aims to produce 100% of electricity from renewable sources by 2050 and achieving climate neutrality in Europe (Bäckstrand, 2022). Given that the shift toward renewable energy must be prioritized to overcome this challenge and to move toward sustainability which is a global necessity, it is crucial to conduct environmental assessments in a critical and systematic manner, because it is closely linked to land-use change and its environmental implications (Kishore et al., 2025). Italy is one of the countries that has actively participated in this plan until now, and it has taken on a prominent role as a leader in advancing it. The Basilicata region in southern Italy is one of the provinces that has been heavily impacted by the establishment of RES (Scorza et al., 2020).

Regarding to the data available on the official website of the Basilicata region (*https://Rsdi.Regione.Basilicata.It/Dbgt-Ctr/*, n.d.), in addition to the wind farms that have been established currently (around 2,100), there are currently 780 structures under development, and there are 230 wind turbines that are awaiting final authorization. Environmental assessments become crucial for the Basilicata region, especially since this region due to its low population and the gaps in its urban planning frameworks has become somewhat marginalized. Additionally, it's important to consider that Italy and the Basilicata region are rich in cultural and natural resources which must be preserved (Gizzi et al., 2019). The Basilicata region is a unique combination of environmental, geological, and cultural heritage. This area includes national and regional parks, notable archaeological sites such as the UNESCO World Heritage city of Matera, and the abandoned town of Craco which showcases a remarkable intersection of natural and human-made features, as well as the region's global significance (Bentivenga et al., 2024). The region also hosts 113 geosites of remarkable educational, scientific, and touristic importance, strengthening its reputation as an "open-air laboratory" for research, environmental education, and geotourism (Pilogallo et al., 2019).

This historical and natural heritage, requires a comprehensive environmental assessment. However, given the aesthetic impacts that wind structures, in particular, have on the landscape, this aspect has always been a focal point in environmental evaluations. Therefore, in this research, our goal is to focus on the impact that wind energy facilities have on the landscape aesthetics of the Basilicata region.

The case study focuses on a cluster of seven municipalities in the Basilicata region; Livello, Montemilone, Venosa, Maschito, Palazzo San Gervasio, Banzi, and Forenza. These areas were selected based on the concentration of authorized RES. Furthermore, given that environmental assessments require ultimate data and a comprehensive understanding of the study area, the initial phase of the methodology involved extensive data collection and preliminary analyses conducted in collaboration with domain local experts. Subsequently, the Scenic Quality Model within the InVEST software was employed to evaluate the aesthetic impacts of wind turbine installations, considering both the current conditions and the proposed developments in the near future.

The research findings, in addition to providing a more realistic perspective on renewable energy, can also highlight the importance of local experts and position Basilicata as a model for European cities. It will demonstrate how the integration and implementation of RES in the region can have environmental implications. The originality of this research lies in the fact that, until now, methods used to assess visual impact have typically relied on conventional approaches, such as viewshed analysis. However, in this study, we employed a newer and more advanced method.

2. Methodology

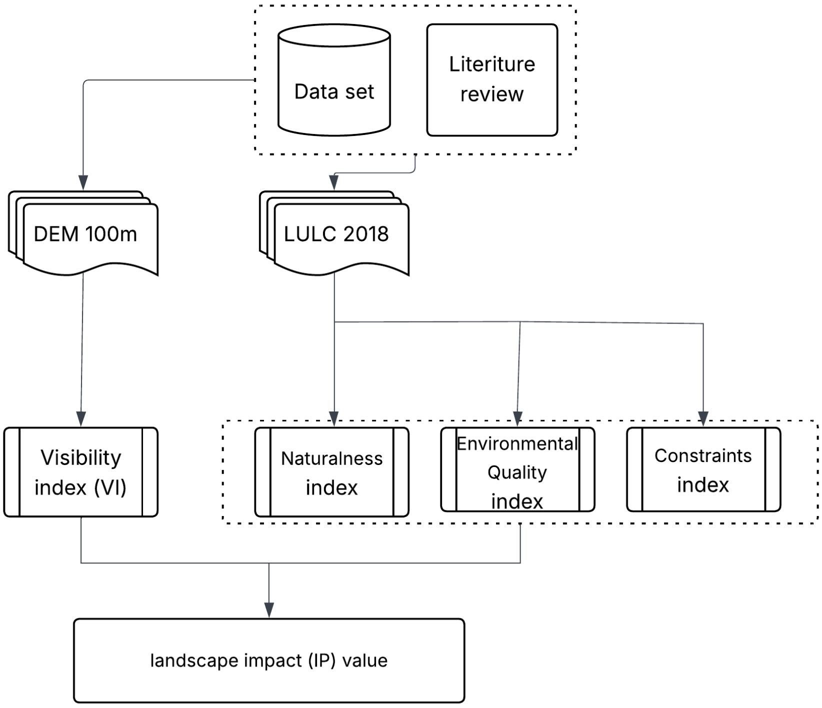

Fig.1 Methodology framework

In the methodology section, as outlined in Fig.1, it is generally divided into three parts. In the first part, we review the theoretical framework, emphasizing the importance of expert opinions and expert-based methods for local and regional projects, as well as identifying gaps and shortcomings in the evaluation methods for the visual impact of wind energy facilities. In the second part, to calculate the landscape value, we employ an expert-based approach. This was carried out during the training period at the *F4 s.r.l*[1] company, which consists of around seventy specialists in architecture, agricultural engineering, environmental science, technicians, legal experts, consultants, and researchers. They collaborated in designing the questionnaires, and the industry specialists, including geologists, have spent about ten years working on environmental bases for projects related to water, energy, and aquatic environments. In the third part, the focus is on calculating the visual impact of wind facilities on the environment, using the InVEST software and the Scenic Quality Model.

1.2 Input data

In the process of selecting indicators for the assessments, careful attention was given to aligning them with upper-level plans and relevant national, international, and European frameworks such as the Basilicata energy plan (CONSIGLIO REGIONALE DI BASILICATA PIANO DI INDIRIZZO ENERGETICO AMBIENTALE REGIONALE, n.d.). Regarding this plan, we can understand what restrictions exist during the selection of indicators, considering the specific characteristics of the study are, and which factors are more significant in environmental assessments, as well as the protocols we need to consider at both local and national levels. Corine Land Cover data of Copernicus for the year 2018, which is the most recent available land use data, is going to apply for the base of analysis in this work. To map the location of wind turbines within the study area, vector point

1 This study was conducted with the collaboration and permission of F4 Ingegneria S.r.l. (Italy, P. IVA 01822640767), an engineering firm based in Potenza, specializing in design, analysis, and technical consulting for civil, environmental, and energy projects.

layers primarily obtained from the official website of the Basilicata region, and GSE website, the primary resource for renewable energy information in Italy. These layers were later updated through orthophoto and google map additionally, using data from F4 a professional company actively involved in local and regional environmental assessments of renewable energy projects in the area. The current number of wind facilities case study sample is 279, and this number is going to increase to 327 regarding regional plan. In summary, the Tab.1 outlines the data used for this research, including both data formats and sources.

Data	Format		Link
Digital Elevation Model (DEM)	Raster (100m)	TinItaly	https://tinitaly.pi.ingv.it/
Corin Land Cover 2018	Raster & Vector	Copernicus	https://land.copernicus.eu/en/map-viewer
Layer points of wind turbines installation for current and future scenario	Vector	Geoportale Basilicata GSE	https://rsdi.regione.basilicata.it/ https://www.gse.it/dati-e scenari/atlaimpianti https://earth.google.com/web/
-UNESCO World Heritage Sites - Monumental heritage - Archaeology assets - Landscape properties - Areas included in the territorial functional ecological system the territory of the Basilicata region - Agricultural areas - Areas in hydraulic and hydrogeological disruption	Vector	Geoportale Basilicata	https://rsdi.regione.basilicata.it/

Tab.1 Input data information.

2.2 Literature review

Expert involvement in landscape assessment

Environmental impact assessment (EIA) of landscapes integrates ecological, cultural, and perceptual analyses, employing quantitative and qualitative models to address the complexity of landscape changes (Medeiros et al., 2021). Not all aspects receive equal attention. Ecological and land-use indicators typically receive the most focus due to their direct connection to habitat quality and biodiversity (Palermo A. et al, 2024). In contrast, cultural and socio-economic aspects, such as cultural heritage and visual aesthetic quality, often receive less consideration (Schüpbach et al., 2020). Over the past three decades, a wide range of methods has been developed to assess landscape values (Solecka, 2019). Two fundamental approaches can be distinguished in the assessment of landscape values: the expert-driven approach and the subjectivist approach(Lothian, 1999).Expert approaches, rely on generalized public preferences for specific landscape features, drawing on foundational research related to landscape perception and visual amenities, expert judgment, and legal frameworks (Dramstad et al., 2006) Such assessments are based on intersubjective values, which, while not objectively measurable, represent broadly shared preferences and are supported by a core set of common landscape values frequently cited in the literature. Existing expert assessments frequently focus on landscape aesthetic quality (LAQ), which is understood as the enjoyment derived from the aesthetic appreciation of landscapes (Solecka et al., 2022). Furthermore, stakeholder engagement and the integration of local perspectives are recognized as essential for defining sustainability objectives, selecting appropriate indicators, and ensuring that assessments reflect both expert knowledge and community values (Dale et al., 2019). Considering that nowadays there is a growing trend of using machine learning in decision-making, it is still important, especially for local and regional plans, to involve field experts. Since the assessment is a process rather than a one-time decision, it is crucial to engage individuals who have detailed knowledge of the plans' history and context (Gennatas et al., 2020). Additionally, because these individuals are human and interact directly with other stakeholders, their experiences can greatly contribute to the decision-making and assessment process. Moreover, these experts are often local residents, and thanks to their background, they have a deep understanding of all the relevant aspects of the area (Maitland & Sammartino, 2015).

Wind turbine visual impacts and methodological gaps

One of the critical points to consider for implementing RES installation is their aesthetic impacts on the surrounding area, especially at a local scale in Italy as a country that keeps many historical and natural sites, one such barrier is the aesthetic impact of renewable energy facilities on the landscape (Wüstenhagen et al., 2007). It is crucial to carefully select their locations to minimize the visual impact of RES installations and increase social acceptance. To emphasize the importance of the visual impact of RES on the landscape, we address a gap identified in the existing literature through, a bibliometric summary generated using the Bibliometrix R package, based on a custom dataset of scientific publications related to RES and their aesthetic and visibility impacts on the landscape. The Tab.2 contains the summary of general information about bibliometrix review.

MAIN INFORMATION ABOUT DATA	
Timespan	2005:2025
Sources (Journals, Books, etc)	103
Documents	174
Annual Growth Rate %	4.69
Average citations per doc	44.44
Author's Keywords (DE)	609

Tab.2 Main information of bibliometrix analysis

The dataset covers a period from 2005 to 2025 by reflecting a sustained and evolving scholarly interest in the visual and landscape impacts of RES. Comprising 174 documents, the dataset represents a relatively small but concentrated body of research that appears to be gradually expanding. The dataset draws on 103 distinct sources, including both journals and conference proceedings, indicating a moderately broad field with contributions spanning multiple disciplines such as environmental science, energy policy, landscape planning, and sustainability. The annual growth rate of 4.69% points to a steady increase in publications over time, suggesting that scholarly attention to the visibility and aesthetic dimensions of RES is gradually gaining prominence in both policy discussions and public discourse. A rich and diverse keyword set (609 keywords) reflects thematic complexity. This likely includes terms such as "landscape integration", "visual impact", "wind farms", "solar panels", "public perception", etc. Average Citations per Document (44.44) is an unusually high citation count, indicating that the field contains high-impact publications, or that some seminal works are highly cited. It also reflects the growing academic and policy relevance of the visibility and aesthetic dimensions in RES deployment. The annual scientific production illustrated in the figure 9 shows steady growth in publication output over two decades, which aligns with the increased deployment of RES technologies and rising public concern over their integration into landscapes. Publication reaches its peak in 2024. Further analysis using Bibliometrix indicates that Italy and Spain are particularly active in this research area. This prominence likely reflects both the regional significance of renewable energy deployment and national priorities related to sustainable landscape planning and policy.

The thematic (Fig.2) map provides a strategic overview of the conceptual landscape within the literature on renewable energy and its connections to landscape and sustainability issues. Dominant "motor themes" underscore the increasing attention given to visual and environmental dimensions in renewable energy research. Meanwhile, the presence of themes such as ecosystem services and territorial planning in the lower-left quadrant points to areas of either emerging or waning scholarly interest, highlighting the need for longitudinal studies to better understand their developmental trajectories.

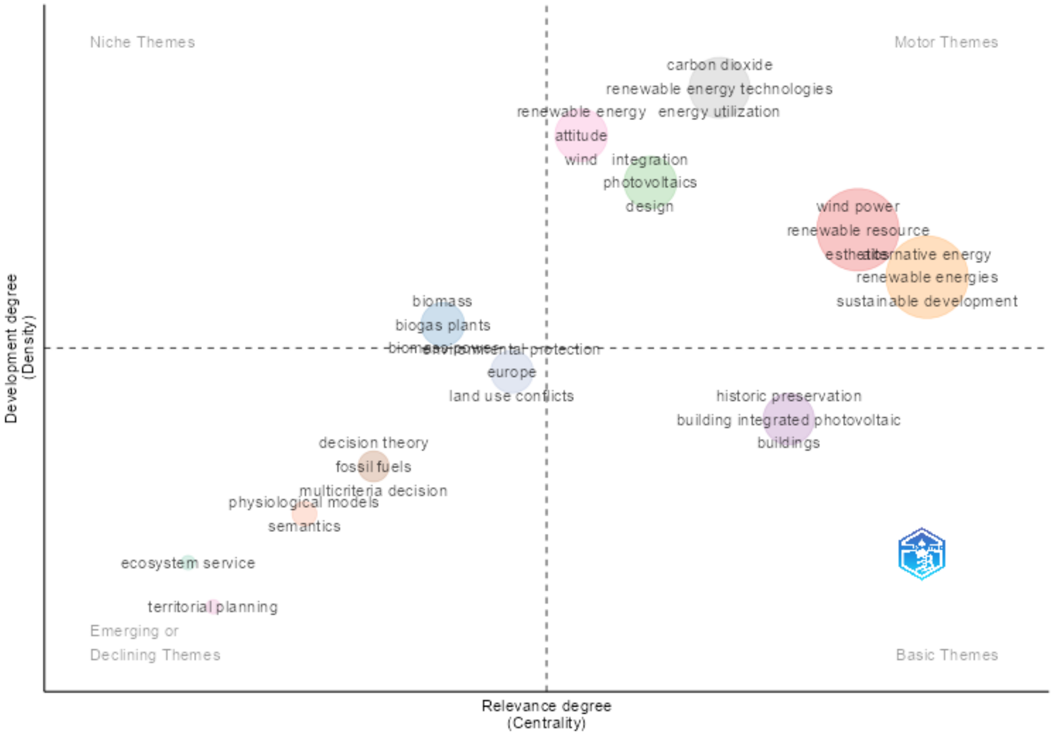

Fig.2 The thematic map offers a strategic visualization of the conceptual landscape

While visual impact emerges as one of the most frequent keywords and suggesting a strong scholarly interest, there remains a lack of standardized methodologies for its assessment. The literature frequently discusses visual impacts of renewable energy installations (especially wind farms), but often relies on qualitative, case-specific, or subjective approaches rather than consistent, replicable tools. This reveals a clear gap between thematic interest and methodological maturity in the field. In this study, we aim to address this gap by employing a GIS-based methodology and by using the InVEST tool, a widely recognized and professional framework for assessing ecosystem services. Through this approach, we seek to elevate the concept of ecosystem services from an emerging or declining theme to a more central topic within the literature.

2.3 Case study

The case study focuses on a cluster of seven municipalities in the Basilicata region (Livello, Montemilone, Venosa, Maschito, Palazzo San Gervasio, Banzi, and Forenza). Selection of areas is based on the concentration of authorized RES installations, as identified in official data published on the Basilicata Region's institutional website (Https://Rsdi.Regione.Basilicata.It/Dbgt-Ctr/, n.d.). Basilicata is an administrative region in Southern Italy, bordered by Campania to the west, Apulia to the north and east (Https://Www.Istat.It/, n.d.). Basilicata is the most mountainous region in southern Italy, with mountains covering approximately 47% of its 9,992 km² territory. The remaining area is composed of 45% hills and 8% plains. Compared to central and northern Italy regions, Basilicata presents relatively favorable spatial conditions for specific types of land use and development, particularly in relation to renewable energy installations and rural land management (Https://Www.Istat.It/, n.d.). Furthermore, in 2018, the Basilicata Regional Authority approved a regional law entitled 'Decarbonisation and Regional Policies on Climate Change' to support the transition toward a low-carbon economy and strengthen climate resilience across the region (Regbasilicata_l.r.-15-Ottobre-2018--n.-32, 2018) (ITALIAN MINISTRY OF ENVIRONMENT AND ENERGY SECURITY, 2022).

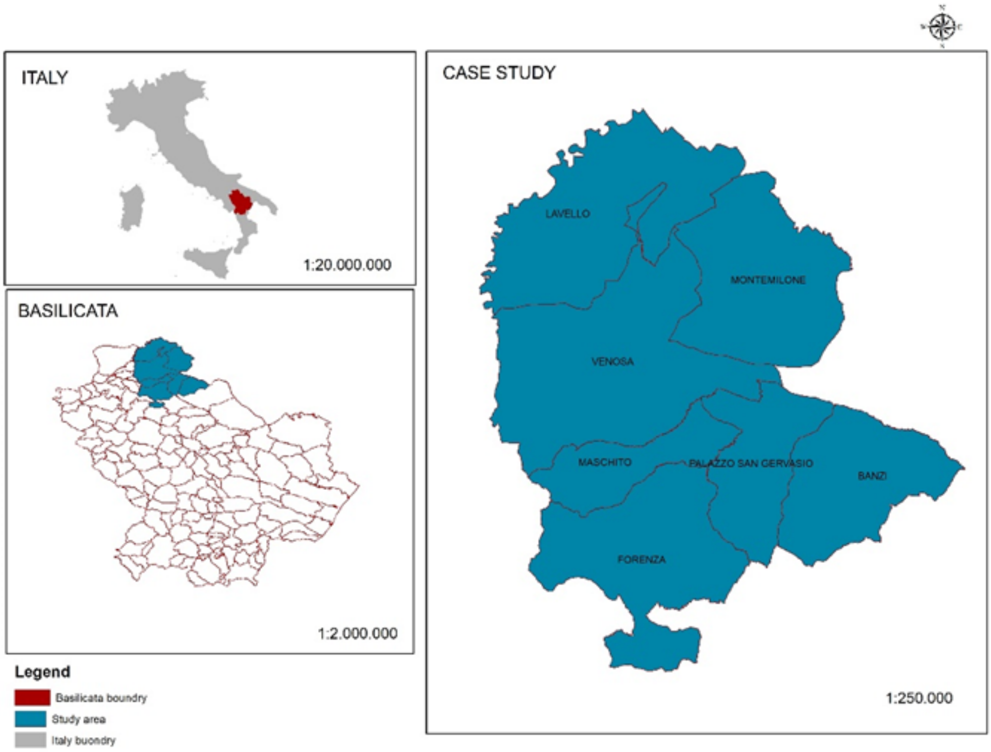

Fig.3 The location of the case study in Basilicata, Italy

2.4 Definition of the visual impact area

Aesthetic impacts on the landscape have long been a central source of opposition to renewable energy projects (Mazzola, 2025). Yet, the current uncertainty regarding the spatial extent and the validity of reported impacts continues to prevent the development of effective strategies for their mitigation (Ioannidis & Koutsoyiannis, 2020). In this paper, the methodology applied for assessing the landscape visual impact of RES is based on a standardized approach that quantifies the degree of visual and contextual transformation induced by such projects, according to the following formula. A common methodological approach proposed by the University of Cagliari quantifies the landscape impact (IP) by calculating two indices; 1) VP index, representing the value of the landscape 2) VI index, representing the visibility of the plant (Loc, 2013). The IP, based on which decisions can be made regarding mitigation measures or system modifications that improve visual perception, is determined by the product of the two indexes.

$$IP = VP * VI \quad (1)$$

The VP and the VI, both expressed on a scale from 0 (no impact) to 4 (maximum impact). VP captures the intrinsic characteristics of the territory through three sub-indices: Naturalness (N), Environmental Quality (Q), and Landscape Constraints (V) according to the formula 2, derived from land use data and spatial overlays of protected or regulated areas. The intervisibility analysis is conducted using DSM-based viewshed models within the Scenic quality model of InVEST software, under different scenarios (current installation and authorized for adding in near future). The final IP raster map is obtained by multiplying the reclassified VP and VI raster maps, enabling a spatially explicit evaluation of visual impact and supporting informed decision-making for mitigation or planning purposes.

$$VP = N + Q + V \tag{2}$$

VP calculation

Evaluating the values attributed to landscapes provides essential insights that can inform landscape policy and support decision-making processes. Over the past thirty years, numerous methods have been developed to assess landscape values. Two primary approaches are commonly distinguished in this field: expert-driven and subjectivist (Lothian, 1999)(Johnson et al., 2024). The following tables present the expert-based values used for calculating landscape values.

The N index was calculated based on land use data derived from the Regional Technical Map (CTR), assigning values from 1 to 10, where 1 represents highly artificial areas and 10 indicates areas with the highest naturalness. Tab.3 illustrates the N value corresponding to each land use classification used in the Basilicata region, at about 74.69%. Following that, with a significant difference, around 13.24% is dedicated to vineyards, olive groves, and orchards, all of which fall under the agricultural lands category. Close to that, about 10% is allocated to broad-leaf forests, which belong to the natural environment category. The remaining percentages are roughly similar, and each is less than 1% for our study area.

	Land Use	**Index N**
Artificially modeled territories	Industrial or commercial areas	1
	Mining areas, landfills	1
	Urban and/or tourist fabric	2
	Sports and hospitality areas	2
Agricultural lands	Arable and uncultivated land	3
	Protected crops, various types of greenhouses	2
	Vineyards, olive groves, orchards	4
Woods and semi-natural environments	Cyst areas	5
	Natural grazing areas	5
	Coniferous and mixed forests	8
	Bare rocks, cliffs, crags	8
	High, medium and low Mediterranean scrub	8
	Broadleaf forests	10
	Maritime waters	8

Tab.3 Index of naturalness and classes of land use

Like the N index, environmental quality values are assigned on a scale ranging from 1 to 6, with each value representing a distinct level of environmental quality linked to various land use typologies. Consequently, areas characterized by more ecologically beneficial or less intensive land uses (e.g., natural habitats or forests) are assigned higher scores. In contrast, areas with more intensive or environmentally degrading uses (e.g., industrial zones or urbanized areas) receive lower scores. Tab.4 included all Q values for each category.

The Q value that can somewhat represent the habitat quality in the study area indicates that over 87% of the area is dedicated to agricultural quality. Following that, with a significant difference, about 10% of the area is assigned to maritime waters. For the remaining habitat qualities, the percentages are roughly similar, and each is less than 1%.

Land Use	**Q Index**
Service areas, industrial areas, quarries, etc.	1
Urban fabric	2
Agricultural areas	3
Semi-natural areas (garrigues, reforestations)	4
Areas with woodland and shrub vegetation	5
Wooded areas	6
Maritime waters	5

Tab.4 Index of environmental quality

In the Regional Energy Plan (CONSIGLIO REGIONALE DI BASILICATA PIANO DI INDIRIZZO ENERGETICO AMBIENTALE REGIONALE, n.d.) of the Basilicata region, the suitability of land for energy production is defined through a set of constraints specific to each type of renewable energy source. In this study, constraint indicators outlined in the energy plan are used, with values assigned to each category. The value scale ranges from 0 to 1 with historical and cultural heritage assigned higher values due to the extensive protection provided by various legal frameworks, although area with hydrogeological, forest, natural feature, and municipal areas have 0.5 value. Hydrogeological sensitive areas, forests, natural features, and municipal zones are attributed an intermediate value of 0.5. A value of 0.25 is attributed to urban areas and river buffer zones, reflecting their comparatively lower constraint level. Areas not falling within the mentioned categories are assigned a value of 0. The Tab.5 presents information on the assigned constraint values for each land category.

Index relating to the presence of constraints	**V value**
Areas with historical-archaeological constraints	1.00
Areas with hydrogeological constraints	0.5
Areas with forest constraints	0.5
Areas with protection of natural features (PTP)	0.5
Municipal areas	0.5
Areas of buffer (about 800m) from urban fabrics	0.25
Areas of buffer, buffers (rivers, sheep tracks, etc.)	0.25
Unconstrained areas	0.00

Tab.5 Index of constraints

In the study area, 21.46% of the total area is subject to restrictions for the installation of these facilities, due to the presence of historical and archaeological values in those areas. The largest percentage of the area, about 38.98%, is allocated to regions with no restrictions. Next, around 26.37% of the area is designated for protection due to the presence of natural features and municipal zones. Finally, the smallest percentage, approximately 13%, is allocated to buffer zones of urban fabrics, rivers, and ship tracks.

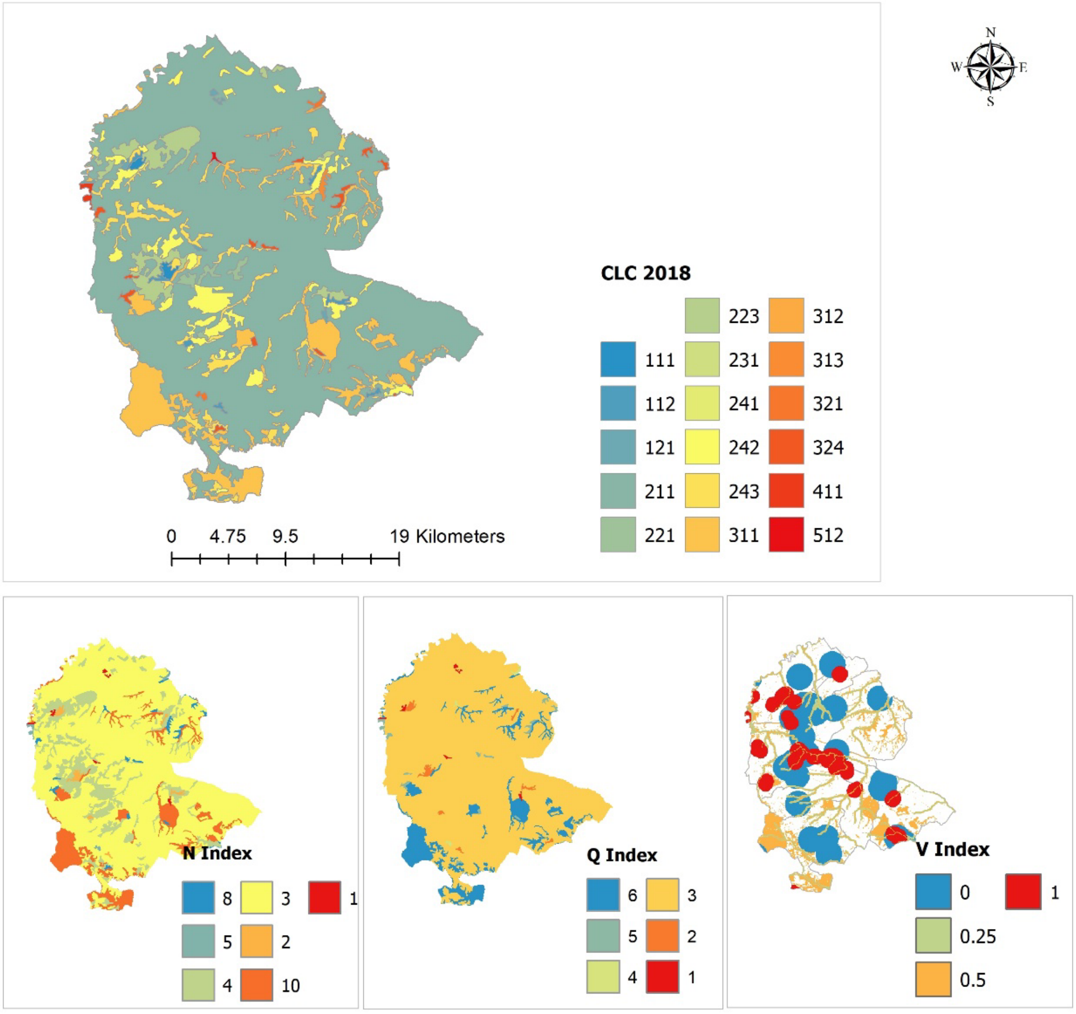

Fig.4 Transforming CLC codes to N, Q and V indexes

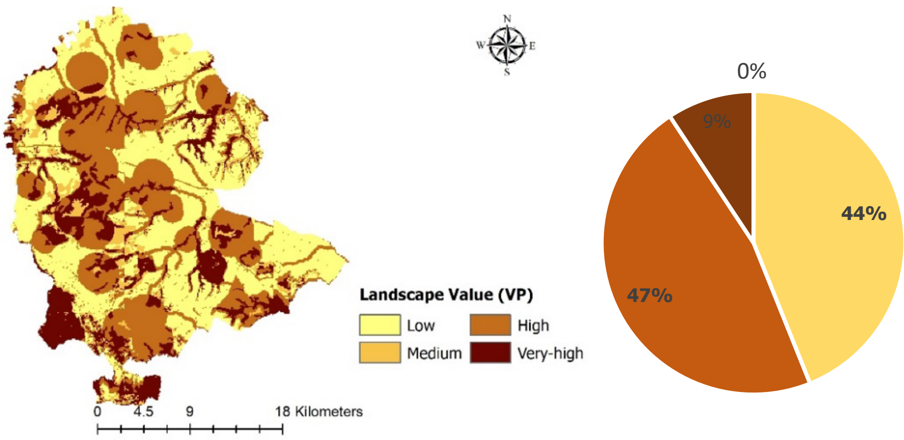

Fig.5 a) Landscape value map for study area; b) landscape value percentage for each class

In the GIS environment, the values of the N, Q, and V indices were summed and resampled on a scale between 1 and 4 according to the methodology described above to derive the landscape value map of the territory. The map algebra operation allows the result to be obtained pixel by pixel. Fig.5 shows overlaid normalized indexes.

The pie chart illustrates the proportional distribution across four categories based on absolute values. The High category constitutes the largest share at 47%, Medium at 44%, and Very High at 9%. Despite having a recorded value of 450,000, the Low category accounts for 0% of the total due to the relative magnitude of the other values.

VI calculation

The visual impact of wind turbines largely depends on their distance from the observer(Bishop & Miller, 2007). Visual impact assessments of wind turbines in Europe have been conducted since the early 1990s. The first reports published by the European Commission in 1995, focusing on the visual analysis of relatively small turbines with a height of approximately 45 meters, indicated that their maximum visibility range extends up to 20 kilometers. Thomas, based on a study conducted in Wales on wind turbines with heights ranging from 41 to 45 meters, demonstrated that the maximum range for visibility analysis should initially be limited to 15 km, later adjusting this threshold to 20 km (Wróżyński et al., 2016). At the turn of the century, increasingly taller wind turbines were constructed, and according to Bishop, their visibility could extend beyond 30 km. However, Bishop argues that beyond 20 km, the visibility of turbines becomes very limited, and their impact is minimal (Bishop, 2002).

In this study, we propose using the Scenic Quality model available within the InVEST software to assess the visual impacts of renewable energy installations. The InVEST Scenic Quality model computes the visual impact of features in the landscape in several steps, and for each structure site, calculate the visibility for each point feature viewshed algorithm. In addition to identifying visible areas, the model also estimates the amenity or disamenity value of visibility by weighting the visibility results and applying the valuation function specified by the user in the interface. By summing the individual valuation rasters, the model generates a weighted aggregate that represents the overall visual impact across the area of interest. The weighted aggregate valuation raster is divided into quartiles to produce a final. The weighted aggregate valuation raster is divided into quartiles to produce a final raster that represents visual quality across the landscape. Additionally, the visibility rasters from all structure points are weighted and summed to generate a raster that reflects the total number of visible points, accounting for their relative importance. The valuation function is computed up to a maximum valuation radius that defaults to 8.000 meters. The following section presents the model's required input data for running the analysis.

The first thing the model requires is defining the study area boundary, also known as the AOI, which is a polygon vector layer. In this study, we used the municipal boundaries downloaded from the official website of the Basilicata region, and the coordinate system has been adjusted to WGS84 / UTM Zone 32N to ensure compatibility with the DEM. furthermore a point vector representing wind turbines that negatively impact scenic quality of study area. Optionally, there are possibilities to enhance the analysis through defining more attributes such as; maximum viewing distance, which limits the extent of the viewshed for each feature, viewshed importance coefficient, which weights the visual influence of each feature, the viewpoint height, which adjusts the elevation from which visibility is assessed. These parameters enable a more precise and context-specific representation of visual impacts. height here defines the maximum length of the line of sight originating from each viewpoint. If this field is not specified, the model will consider all pixels in the DEM during the visibility analysis. For this study, we used the actual height of each wind turbine as provided in the dataset. In cases where height data was missing, we assigned the average turbine height, which is 150 meters. Additionally, a radius value was included in the attribute table, with 30 km. This distance corresponds to the typical visibility range of a 100m high turbine. Fig6. shows generated rasters that represents the visual quality of each pixel across the study area for both current situation and authorized installation as future scenario. The cells of the raster are classified based on percentile breaks, allowing for a relative assessment of visual impact.

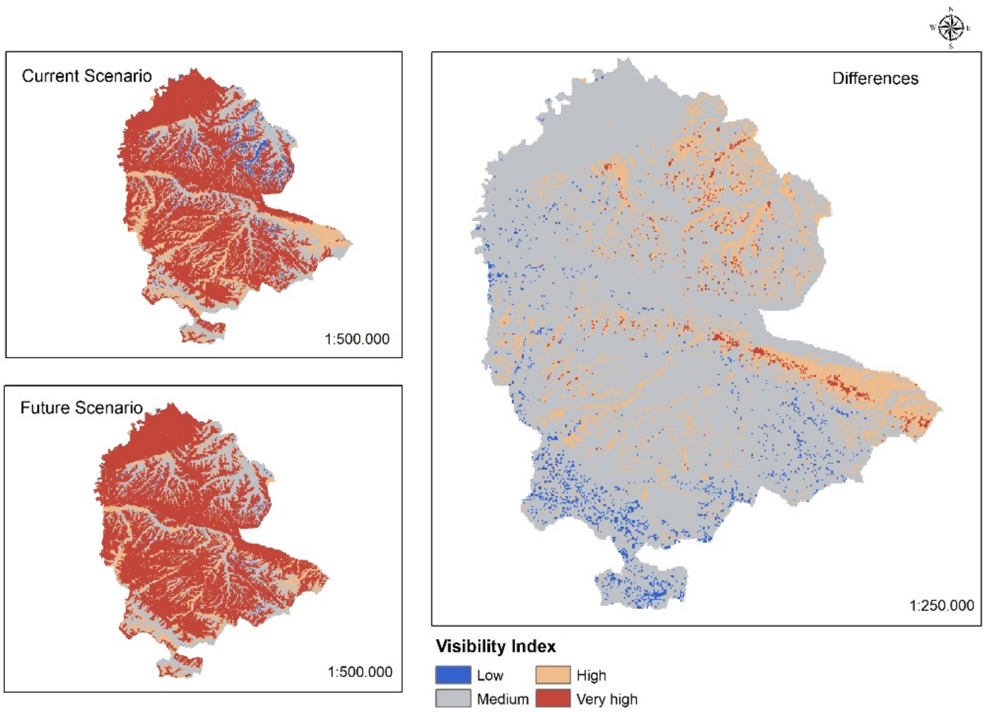

Fig.6 Comparison between current and future scenarios of the visibility index

The Fig.6 shows for both the current situation and the predicted future scenario, the impact of these wind turbines on the environmental visual quality of the study area falls primarily into category four, meaning the impact is very high. Currently, this impact is about 60.35%, and with the addition of future wind turbines, this percentage increases by 5%, reaching around 65.10%. At the same time, the current category one impact, which is about 13.14%, will decrease in the future to approximately 11.08%, and this category will then shift into category four. Meanwhile, for category two, which indicates a medium-level impact, both the current and future scenarios remain relatively stable.

Overall Impact of Visual Disturbance on the Social Value of the Landscape

Finally, considering all the analyses carried out so far, in this section we will present the results that address the main objective of this research: examining the impact of wind turbines on the visual value of the study area's landscape. Tab.4 illustrates the IP index percentages which is derived from the overlay of all the indicators we have discussed so far, along with their normalization and, ultimately, their reclassification into four classes: low, medium, high, and very high. This figure includes both the current state, the future state, and the differences between these two timeframes.

IP Value	IP Scale	Sup. ha	Sup. %	Sup. ha	Sup. %
		Current		Future	
Low	1	13,282	18.41	14,547	14.76
Medium	2	29,637	10.72	27,493	9.2
High	3	7,427	39.57	6,601	42.5
Very high	4	20,997	31.3	22,702	33.53

Tab.4 Landscape value impacted by wind turbines

The results show that, for the two timeframes analyzed both the current state and the future projections, the magnitude of changes in the high and very high categories is evident for both periods. Notably, the change in the first category representing low impact, has decreased in the future scenario, meaning the difference is about 4% smaller in the future. On the other hand, the difference has increased for the fourth category, which has the greatest impact on the visual landscape of the area.

3. Result

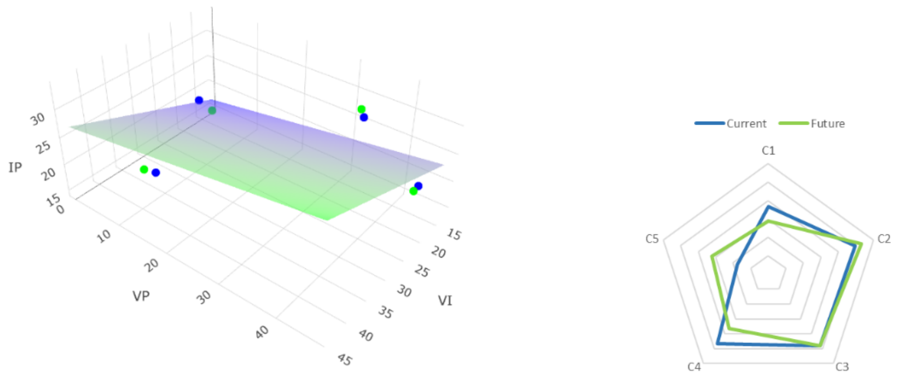

Fig.7 a) VI and VP relation con IP; b) Comparison of VI and VP impact on landscape value changes

The Fig.7b, Compare the impact of wind turbines on landscape value in the current scenario with the projected impact under future installation scenarios. The results indicate that, although the medium impact class (C3) remains constant across both scenarios, the proportion of areas falling into the C5 category, representing very high impact, is projected to increase from 9% to 16%. On the other hand, a 3D regression plot (Fig.7a) shows how two independent variables, VI and VP, together explain changes in IP. The colored surface in the 3D graph, displayed as a semi-transparent plane, represents the regression plane generated by a multiple linear regression model. This plane visualizes the fitted values of the IP as a function of the combined influence of the two explanatory variables. The green surface, corresponding to the future scenario, is positioned higher than the blue surface representing the current state. This change reflects a steeper gradient, implying a more pronounced increase in the landscape impact of wind turbine installations in the future. Although the overall landscape value remains constant between the two scenarios, the shift toward a more concentrated presence of high impact classes suggests increasing visual dominance and changing perceptions of landscape disturbance.

4. Conclusion and discussion

One of the findings of the research highlights, even with new approaches to decision-making processes, experts, especially local specialists who have been involved in environmental changes and driving factors over time, are essential and crucial. Environmental impact assessments sometimes require straightforward, practical steps rather than complex methods that can lead to confusion when many factors are not influential. Therefore, the role of these specialists should not be overlooked, and more opportunities for collaboration among stakeholders, such as academics, engineers, planners, economists, and policymakers, should be provided. It is important that, in the decision-making process, we always consider reliable plans at both the national and regional levels, and that the interests of all stakeholders take precedence over the benefits of any single group in planning and assessments. The results also show, it is possible to make a smart choice of assessment methods where needed, tailored to the type of impact. For instance, in the case of wind facilities, considering the nature of these structures and the residents' criticisms, especially regarding visual and landscape impacts, which have been a significant source of opposition goes beyond just the economic benefits and the cleanliness of the energy. If a one-dimensional harm from these technologies' increases, then, no matter how clean the energy is, it could ultimately become harmful to the environment. For this reason, we used the Scenic Quality Model through the InVEST software, which is originality of this work, because until now, most of the research conducted on the visual impact of wind facilities on the area and on the Basilicata, region has typically relied on conventional methods, such as viewshed analysis available in GIS programs. However, this model, in addition to what viewshed analysis offers, also considers dimensions and scales, which are critical and decisive factors in how these facilities affect the landscape of the studied area. Furthermore, the assessment conducted in this research has issued warnings to future projects and facilities that are planned to enter the region. Given the current state and the significant impact on the landscape and aesthetic quality of the studied area, the assessment warns that adding these facilities will further increase these impacts. This poses a serious threat to the region, which, due to its relatively low population and moderate economic situation compared to other Italian regions, could see its role at both the national and international levels weakened.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 3.5 to improve the readability of parts of the text. After using this tool/ service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Image sources

Fig.1: Methodology framework, Author generated;

Fig.2: The thematic map offers a strategic visualization of the conceptual landscape, R generated;

Fig.3: The location of the case study in Basilicata, Italy, Author generated;

Fig.4 Transforming CLC codes to N, Q and V indexes, Author generated;

Fig.5a: Landscape value map for study area. b) landscape value percentage for each class, Author generated;

Fig.6: Comparison between current and future scenarios of the visibility index, Author generated;

Fig.7a: VI and VP relation con IP. b)Comparison of VI and VP impact on landscape value changes, Author generated.

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