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How do climate change-driven renewable energy infrastructures affect the visual perception of landscapes? An exploratory empirical study

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***Abstract* – Considering the increasing installation of green energy production infrastructures, this preliminary study investigates the visual perception of rural landscapes in the Lucanian Apennines (Basilicata, Southern Italy) by analysing the gaze behaviour of a selected group of participants through eye-tracking approach. The results provide some empirical and introductory evidence for perceptual hierarchies and for visually preferred landscape characteristics involved in landscape appreciation, which will help further the discussion on character assessment and visual impact analysis in geographic inquiry.**

I. INTRODUCTION

At the core of the political and strategic priorities of the European Union is to tackle global climate change. In particular, through the "Clean Energy for All Europeans" package the European Commission aims to speed up the clean energy transition within the EU by 2030. [1]. Several other important measures derive from these legislative measures. Of these, Directive (EU) 2018/2001 of the European Parliament and of the European Council concerns the promotion of the use of energy from renewable sources [2]. Furthermore, the Communication of the European Commission entitled "European Green Deal" [3] lays down the programmatic lines of a new strategy for a sustainable European economy and ultimately Regulation (EU) 2021/1119 sets out the framework to achieve climate neutrality [4]. More and more invested in the promotion and development of new strategies of sustainable economic growth and greenhouse gas decreases, the EU has thus speeded up the development of renewable energy systems. The consequence has been, especially over recent years, a remarkable increase in the number of renewable energy facilities in urban, periurban, rural, and offshore areas across Europe.

According to the statistics published by the International Renewable Energy Agency (IRENA)[5], the biggest installed renewable energy today in the European countries, with a dominant majority of solar and wind power, are Germany at 184 GW of installed power, Spain at 92 GW, France at 74 GW and Italy at 72 GW of renewable power. For Italy, the Basilicata region (Southern Italy), similar to the rest of Southern Italy, is thus undergoing a progressive transformation of land use in its countryside. Traditional agricultural and pastoral uses are increasingly giving way to energy-oriented land uses, with the proliferation of wind turbines and photovoltaic fields. In fact, throughout the Basilicata region, 18,678 photovoltaic systems are now operational, with a total power of 518 MW, and 1,478 wind systems are installed, with a total power of 1,506 MW [6]. This phenomenon is often linked to the ongoing depopulation of inland areas along the Apennine range, where, in the face of a substantially stable national population, census data highlight a decline in the population of Basilicata which has recently reached an annual rate of approximately -0.8%, due to a natural balance and, above all, a migratory balance which are both negative [7].

These developments highlight the importance of examining the visual interplay between emerging green energy production infrastructure and the established forms of the traditional landscape. This concern is particularly relevant in Basilicata, where the landscape is recognized as a valuable environmental and cultural resource, potentially serving as a foundation for future sustainable economic development and as a tool to counteract depopulation and abandonment.

The present research aims at proposing an evaluation approach for perceived Landscape Quality through an analysis about responses collected through eye-tracking approach. As identified in previous research [8], eye-tracking has proven quite effective in objectively assessing the user-perceived physical features of landscapes and their component elements. Eye-tracking provides an empirical, data-based approach for capturing observers' visual behaviour using records of eye movements and areas of fixation, hence determining which elements of the

landscape capture viewers' attention. The working hypothesis is that eye-tracking can enhance the objectivity and defensibility of visual impact assessments, improving our understanding of landscape preferences and supporting more informed and transparent spatial planning decisions. The case study chosen as test site is an inland Apennine area of the Basilicata region, close to the Potenza chief-town.

II. DATA AND METHODOLOGY

Eye-tracking technology makes it possible to record a subject's eye movements upon looking at a scene, picture, or video, allowing researchers to identify what is seen, how long, and in which order [9]. For this study, a panel of 28 university students (18 female, 10 male) from the Piacenza campus of the Università Cattolica del Sacro Cuore, aged between 22 and 25, was selected. Each participant, after being briefed on the general procedures and requirements of the experiment, conducted their observation while seated approximately 50 cm from the eye-tracking device screen. However, in order to minimize bias and preserve the impartiality of students' visual attention, they were not informed of the specific aim of the study. Following a calibration phase, each subject was shown ten images of rural landscapes interspersed with unrelated control images to reduce the risk of pattern recognition or biased attention. Each image was displayed for 7 seconds. All collected data were considered valid, with gaze capture rates exceeding 80% for each participant. The eye-tracking device employed was the Tobii Pro Fusion, operating at a sampling rate of 120 Hz. Data collection and management were carried out using the Tobii Pro Lab software (version 1.241). This paper reports the results of the heatmap fixation analysis, which represents the cumulative duration of gaze fixations on specific areas within the viewed images. These heatmaps visually illustrate the areas observed, along with varying levels of visual interest indicated through colour gradients. In particular, red regions within the heatmap reflect areas where people gazed for longer durations, while green regions reflect areas where people's vision was for shorter durations, and transparent areas reflect regions that received no visual attention. The image set submitted to the students consisted of photographs taken on March 1, 2025, in a rural area located between the municipalities of Pignola, Tito, and Satriano di Lucania in the Basilicata region. The selected photos represent typical Apennine rural landscapes featuring diverse anthropogenic elements. For instance, photovoltaic fields captured visual attention both when situated in the foreground and in more distant background settings. In other cases, these same elements attracted limited attention, likely due to the concurrent presence of more visually or semantically g., cultivated fields, farmhouses, residential buildings, roads, utility poles, wind turbines, photovoltaic fields), natural elements (e.g., lakes, mountains, forests, grasslands), and historical-cultural landmarks (notably, the Norman-era medieval tower known as the *Torre di Satriano*, depicted in some of the images). All photographs were captured using a SONY DSC-HX100V digital camera under favourable weather conditions (clear or lightly clouded skies), ensuring optimal visibility and consistent lighting conditions.

III. RESULTS AND DISCUSSION

The heatmap of Fig. 1 reveals that visual attention was primarily focused on the small cluster of buildings located at the centre of the scene. This is likely attributable to the natural tendency of centrally positioned objects to draw greater interest [10]. A secondary area of focus was the pair of wind turbines on the right, likely due to their chromatic contrast with the background. Similarly, noticeable visual attraction was also exerted by a small white dot (wading bird) and another group of houses located on a hillside. In addition, wind turbines located along the far-off ridge themselves gained non-trivial amounts of visual attention. Similarly, in Figure 2 the heatmap shows a concentration of fixations on the centrally located cluster of buildings, followed by attention directed toward one of the two wind turbines on the left side of the image. A road sign in the centre, despite its small size, generated a certain visual interest due to its chromatic contrast [11]. Additional focal points included a group of buildings on the right and landscape features such as rows of trees and shrub boundaries delineating agricultural parcels. Contrary to what has been observed so far, the heat map of Figure 3 shows that visual attention was drawn to elements that are not centrally located but exhibit visual salience, such as the rocky peak in the upper left and the photovoltaic field below it, the latter despite lacking strong chromatic contrast. Further areas of interest included a cluster of wind turbines on the right, a quarry, and other wind turbines located in the background. Built structures in the centre and foreground also captured measurable visual attention. Examining the heat map of Figure 4, it emerges that the most visually salient areas were positioned at the right (wind turbines) and left (group of houses) edges of the observed landscape. Once again, the centrally located buildings exerted strong visual attraction, greater than that of the nearby photovoltaic fields. Particularly striking the strong attention directed toward the green meadow on the right, which is likely explained by the intense chromatic contrast it creates with its surroundings. The photo in Figure 5 shows that the landscape is dominated by expansive photovoltaic fields, which attracted diffuse but low-intensity attention across their full extent. In contrast, the rocky peak at the upper left and the top of a transmission tower below had greater visual salience. The latter can be explained by people's tendency to focus on seeing complexities [12; 13]. Central areas, including buildings in the foreground and middle ground, again attracted significant attention, along with the distant wind turbines visible in the background on the right. Figure 6

shows the most visually salient feature was the tip of a wind turbine located on the left side, which stands out due to its chromatic and geometric contrast with the surrounding landscape. The perceived complexity of the nacelle at the top of the turbine further enhanced its salience. Lower-intensity visual attention was more widely distributed, with some focal points along the ridgeline, in the centre of the image. Also noteworthy was the attention captured by the snow-covered peak in the background and a structure located in a wooded area in the lower right. Figure 7 shows that visual salience was primarily concentrated on a historical monument, the *Torre di Satriano*, an impressive Norman tower located on the top of a rocky hill guarding the fortified settlement of the ancient *Satrianum* [14]. Additional fixations were directed toward centrally located anthropogenic features, as well as a wind turbine situated on a distant ridgeline to the left and a building on the far right. Therefore, the tower emerged as the dominant visual attractor, emphasizing the influence of cultural landmarks in landscape perception. Similarly, in Figure 8 the *Torre di Satriano* again stood out as the most visually salient element although placed in the background of the photo. However, strong visual attention was also drawn to the upper section of a wind turbine likely due to perceived structural complexity [12; 13] as well as to the series of photovoltaic panels in the lower right, which form a distinct repetitive pattern. Anthropogenic elements located at the base of the hill on which the tower stands, along with distant wind turbines on the left, also attracted high attention. Therefore, a form of competition arose between cultural and anthropic elements, with the latter seemingly exerting a perceptual and cognitive interference on the cultural landscape. In Figure 9 the two wind turbines served as the primary visual attractors. Their impact can be attributed to their vertical form, the rotational symmetry of the blades, and their chromatic and geometric contrast against the hilly background. In contrast, scattered buildings and settlements in the valley received minimal visual attention. Their low contrast, small size, and peripheral placement in the visual field likely contributed to their reduced salience. Similarly, the barren foreground at the bottom of the image attracted almost no fixations, likely due to its uniform coloration, lack of distinctive shapes, peripheral framing, and low semantic relevance compared to more iconic elements like wind turbines. This distribution of attention underscores the combined influence of visual salience (shape, contrast) and semantic value (presence of meaningful objects) in guiding gaze behaviour in landscape environments. Finally, in Figure 10 the *Torre di Satriano* located atop the hill again commanded the highest concentration of visual attention. This can be attributed to its elevated, isolated position, which made it a natural focal point within the composition. The tower also served as a historical and symbolic landmark, contrasting strongly with the surrounding natural elements. While scattered residential buildings showed a more diffuse attention pattern, those with brighter colors or positioned strategically (e.g., at the hill's base or near the visual center) received more fixations. The photovoltaic field in the lower left side registered very limited visual attention. This may result from a low semantic salience the panels were not perceived as emotionally or symbolically significant in this context and from their low positional prominence, as elements located near the bottom edge of the frame are naturally less likely to be explored [10]. Overall, visual attention in this image appears to be guided primarily by symbolic and elevated elements (e.g., the tower), followed by scattered residential features, while technological components such as solar panels, although clearly visible, attracted limited attention. This suggests that landscape perception is

Figure 1

Figure 2

Figure 3

Figure 4

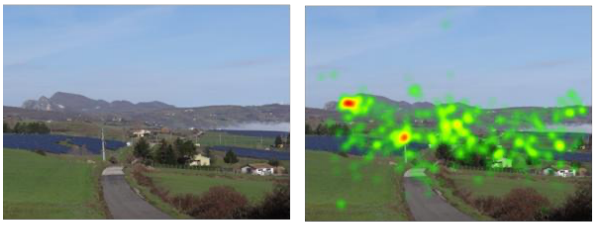

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

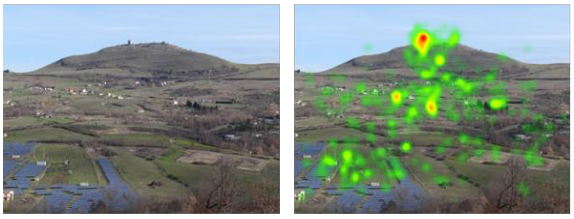

Figure 10

influenced not only by form and position, but also by semantic and cultural significance of the observed objects.

IV. CONCLUSION

The analysis of heatmaps reveals a significant regularity in the visual perception of recurring landscape components. Across all the examined photos, consistent categories of landscape elements were identifiable although differing in number and spatial arrangement and, in most cases, the same elements uniformly captured the observers' attention, with only a few exceptions. It emerges that elements exhibiting clear chromatic, geometric, or symmetrical contrast, even when located in the background, consistently attracted significant visual interest. This is particularly evident in the case of wind turbines and power transmission towers, regardless of their positioning within the visual field. Attention was also notably directed toward elements that, although less prominent in terms of colour, nevertheless introduced a degree of textural or structural discontinuity in otherwise homogeneous landscape contexts. For instance, photovoltaic fields captured visual attention both when situated in the foreground and in more distant background settings. In other cases, these same elements attracted limited attention, likely due to the concurrent presence of more visually or semantically dominant features (e.g., the historical tower or wind turbines), or due to positional factors.

Summarizing, the high visual impact caused by anthropic elements appears to condition a kind of perceptive and cognitive interference, which affects full enjoyment of the cultural landscape. Viewers, as a matter of fact, concentrate their attention upon technical aspects instead of those carrying symbolic, historical or identity connotations, often relegating these latter ones to a marginal or secondary position in overall attention. This aspect underlines how an increasing spread of energy networks in inner rural areas can pauperize the aesthetic and cultural enjoyment of the landscape. Within an environment such as Basilicata, where wide-ranging cultural heritage constitutes a strategic asset for sustainable development, such competition is relevant from a planning and conservation perspective. A critical reflection upon integrating anthropic elements into the environment is therefore needed, in order for them not to undermine readability and identity connotations of the landscape. These preliminary findings show the effectiveness of eye-tracking approach for evaluating the degree of visual attention elicited by anthropogenic components of the landscape. However, further investigations will be oriented at validating and expanding these prelusive deductions.

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