A methodology for the assessment of visual impact caused by renewable energy facilities on the landscape in cultural heritage sites.

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Abstract

Renewable energy facilities, especially wind and solar facilities, have given rise to several conflicts due to their visual impact on the environment. This is due, among others, to their proliferation, extension, and placement, often in highly visible locations.

The current methodologies used to assess the visual impact of these facilities on the landscape do not generally consider such important aspects as cultural heritage or local values.

This article gives a full description of the "Cultural Method", a novel visual impact assessment methodology with a cultural emphasis, permitting the assessment of the visual impact caused by renewable energy facilities on the landscape in the vicinity of cultural heritage sites. The application of the Cultural Method needs of several steps to include important values of local cultural heritage into the assessment process: delimitation of the area of study and the Area of Visual Influence, preparation of the required cartographical data, analysis of the convergent visibility of the area of study, analysis of the visual quality and visual fragility of each Zone of Potential Concentration of Observers in order to calculate the partial visual impact for each one of them, weighting each partial visual impact by the survey results and a final calculation of the total visual impact. The development of this methodology was tested successfully using various case studies of cultural heritage sites declared Asset of Cultural Interest. Its implementation brings public administrations new possibilities for decisions concerning RE facilities near cultural heritage sites which would be protective with the landscape.

Highlights

- Renewable energy facilities have an impact on cultural heritage sites.
- Current visual impact assessment methodologies do not consider cultural aspects.
- The *Cultural Method* is a new methodology based on perceptual parameters, both qualitative and quantitative considering cultural parameters, the environment and public opinion to assess the visual impact of RE facilities on the landscape in the vicinity of cultural heritage sites.
- The *Cultural Method* assign a fundamental role to public perception of environmental impact of renewable energy facilities on local landscape by including public opinion among factor analysis.
- This methodology will allow public administrations to carry out their own studies and assessments of the visual impact of RE facilities in the vicinity of their cultural heritage sites, thus favouring the protection, management and regulation of territories in accordance with the European Landscape Convention.

Keywords

Methodology
Visual impact
Renewable energy
Wind farm
Solar farm
Landscape
Cultural heritage
Setting
Cultural Method

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Word Count

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List of abbreviations

RE	LIDAR	I_c	I_{zcpo}	M_i	n	C_T	I_{vpe}
ELC	DTM	I_i	P_t	I_v	C_t	A_{cc}	I_{vt}
EIA	DSM	I_{cal}	LR	I_{vv}	C_v	D	
ETRS89	CNIG	I_{caa}	A_t	I_{vh}	D_v	E	
AVI	BTN25	I_{cpz}	DE	α	D_e	I_{vp}	
ZPCO	MFE50	I_{cezcpo}	I_{CT}	β			

1. Introduction

Renewable energy (RE) facilities have given rise to several conflicts due to their visual impact on the landscape, their profusion, their extension, and placement in highly visible locations. With the Charter of Krakow and the European Landscape Convention (ELC), the natural environment came to be regarded as a cultural heritage that could be protected. Thus, within society there arose the dichotomy between the need to increase the production of clean energy through RE installations, necessary for environmental sustainability, and social concerns about the visual impact of these facilities on the landscape.

Over the last twenty years a great deal of research has been conducted into the visual impact of wind farms and solar power plants [1-18]. None of these analyses the visual impact of these facilities on the landscape in the vicinity of cultural heritage sites. Nor are studies of this kind necessary in Environmental Impact Assessments (EIA) despite research showing that a number of constructions in the vicinity of cultural heritage sites impact their contextualisation and enjoyment [19]. There are increasing calls for EIA to incorporate the integration of cultural heritage sites into their local landscape and the inclusion of values of local cultural heritage into the assessment process [16-18, 20, 21]. This research is based on the premise that existing methodologies do not adequately adapt to the characteristics of these landscapes. Previous research studies were never conducted with both kinds of installations, wind and solar (including photovoltaic and concentrators or solar towers), and viewsheds considering the RE facilities and the cultural heritage site at the same time. However, the cultural importance of cultural heritage sites needs to be recognised [16-21].

The framework in which this methodology is developed is based on the premise asserted by Martínez de Pisón, among others, that any cultural heritage has a cultural importance that needs to be preserved. He explains landscape as a multiple cultural construction work. In the same way, Ortega Cantero claims landscape is closely linked to nationalities due its historical meaning and memory. The cultural importance of a cultural heritage could be valued by different parameters. Visibility studies of the RE facilities and the cultural heritage site need to be carried out through Geographical Information Systems (GIS mapping) using a mixed methodology -quantitative and qualitative- of general application which takes into account public opinion through surveys, intrinsic importance and the cultural importance of the cultural heritage site, taking into account importance in popular culture of the area and the different appearances of this heritage in literature, art, etc [16-21].

The aim of this paper is to give a full description of the Cultural Method in order to be applicable as a general methodology for the evaluation of the visual impact of RE facilities on the landscape in the vicinity of cultural heritage sites. The total visual impact has been modulated according to the classes that the Environmental Impact Assessment Law in Spain typify. That classes coincide with most European laws.

2. Methodology and tools used in the research

The research project was conducted in several phases. Firstly, a bibliographic review was made of current visual impact assessment methodologies for RE facilities (wind and solar farms), and the evolution of attitudes towards the natural landscape since the rise of naturalism in the late 18th century with Humboldt to contemporary notions of cultural heritage. The search engines “Google Scholar”, “Dialnet”, “Teseo” and “Elsevier” were used with the key words “visual impact”, “landscape”, “landscape impact”, among others.

Secondly, various case studies were analysed following different visual impact methodologies such as the Spanish method, OAI multicriteria indicator or MOYSES v4.0 [2, 5, 22-25]: the wind and solar RE facilities constructed and planned in the vicinity of the monumental ensemble of Uclés, the Segóbriga Archaeological Park and the Way of Saint James at the *Alto del Perdón* in Navarre [16-18]. These case studies permitted us: 1) to verify the current EIA methods to evaluate the visual impact of these facilities; and 2) to test, by means of surveys of the local populations of Uclés, Saelices and Tribaldos, the perception of residents of these facilities and their impact.

A new methodology was therefore developed, named the *“Cultural Method”* which is based on perceptual parameters, both qualitative and quantitative, whose added value is introducing cultural parameters to assess the visual impact of RE facilities on the landscape in the vicinity of cultural heritage sites. Two study cases were used in the development of this methodology: The Carrascosa Wind Farm, in the vicinity of the monumental ensemble of Uclés, declared Asset of Cultural Interest in 1931; and the Photovoltaic Solar Plant of Saelices, in the vicinity of the Segóbriga Archaeological Park, also declared Asset of Cultural Interest in 1931 [26; for an in-deep description].

Various types of software were used: Esri ArcGIS 10.5 for the analysis of viewsheds and mapping; Autodesk AutoCAD for the creation, modification and management of 2D map viewing; SPSS for the statistical analysis of the surveys; Microsoft Excell to enter the quantitative data of the different tables to evaluate visual quality and fragility and the calculation of the Visual Impact Assessment; and Microsoft Word for writing the report of the results.

The data were collected from three sources: field work, map viewers and digital mapping. Field work is always fundamental to visual impact assessment given the abstract nature of maps. In our case, field visits were carried out prior to conducting the Geographical Information System (GIS) analyses. After these analyses, further field visits were made to verify the data in situ and to identify sensitive points from which to carry out the visual impact assessment. Photographs were taken from these positions, choosing clear days with the best visibility conditions. Field notes and maps were drawn up to facilitate this part of the assessment.

Several map viewers from different websites were used for rapid and agile verification of many aspects of the landscape using various maps and thematic map layers.

As the research was conducted in Spain, the digital *European Terrestrial Reference System* 1989 (ETRS89) was used. The sites were located in the Castilla-La Mancha region and the research coordinates was ETRS89 UTM H30N. Some difficulties were encountered as the national digital cartography omits a great deal of data referring to Asset of Cultural Interest and other types of heritage sites. It was therefore necessary to complete the information manually.

The development of this methodology to assess the visual impact of RE facilities on the landscape in the vicinity of cultural heritage sites is presented below, after being tested in two case studies [26].

3. Development of the methodology: *Cultural Method* (Diego, 2020)

The Cultural Method was developed in several steps: 1) the delimitation of the area of study and the Area of Visual Influence (AVI), 2) preparation of the required cartographical data, 3) analysis of the convergent visibility of the area of study, 4) analysis of the visual quality of each Zone of Potential Concentration of Observers (ZPCO), 5) analysis of visual fragility from each ZPCO, 6) calculation of the partial visual impact for each ZPCO, 7) weighting the partial visual impact for each ZPCO by the survey results and 8) calculation of the total visual impact. Fig. 1 shows an overview of the Cultural Method. These steps are developed in detail in following sections.

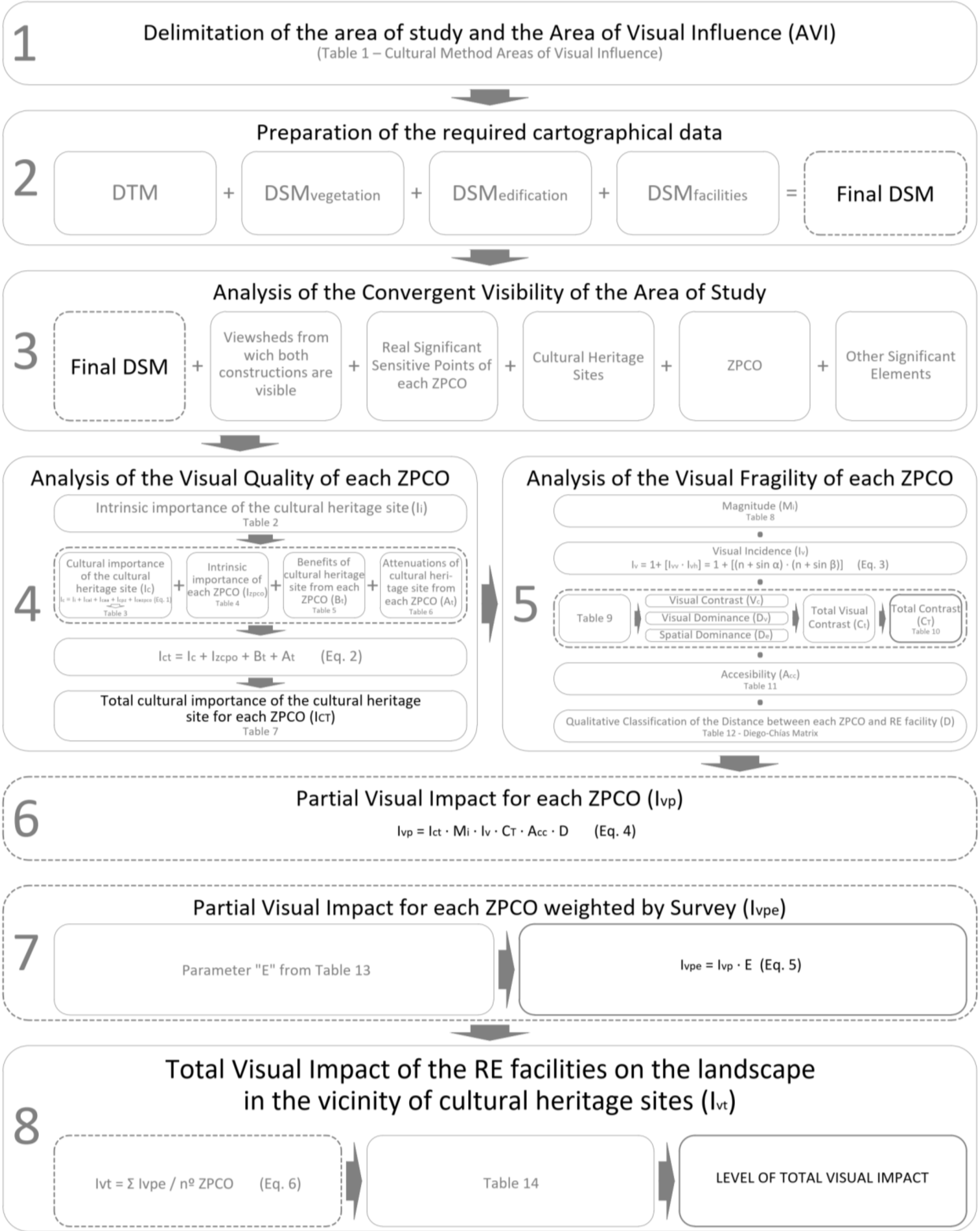

Fig. 1. Cultural Method overview

3.1 Delimitation of the area of study and the Area of Visual Influence (AVI)

The area of study is defined by the landscape in the vicinity of a cultural heritage site where the visual impact of an RE installation is being analysed. It is recommended in consider the geographical, cultural and natural characteristics of the area, the energy and regulatory framework for RE as well as the RE facilities project which will impact the landscape of the cultural heritage site which is taken like case study.

The AVI of the RE facility must be delimited in order to subsequently select the digital models of the area. This area will depend on three factors: the orography of the site, the type of facility and its size. For solar power facilities there are few tables regarding their AVI [27]. However, for wind farms there are a number of studies which have classified different thresholds at which these facilities are visible depending on their size. Bishop [1] has set certain distances at which wind turbines of up to 78 m in height have a visual impact: 8.5 Km for severe impact, 10 Km for moderate impact and over 10 Km for slight impact. Sinclair [28] adapted the *Thomas algorithm* for wind turbines of up to 100 m in height. For turbines 90-100 m in height the thresholds of visual impact are: <4 Km high impact, 4-8 Km medium-high impact, 8-18 Km medium impact, 18-23 Km slight-medium impact and 23-30 Km slight impact. Vissering [29] suggests an AVI of 40 Km for modern, 2 MW wind turbines as, in good weather conditions, these can be seen from a distance of 24 to 32 Km. Sullivan [10] proposed a matrix for the maximum visibility of wind farms with turbines of 90-120 metres in height in relatively flat regions, establishing an AVI of 48 Km with the limit of casual visibility at 32 Km and the limit of visual dominance at 16 Km. Manchado [14] extrapolated the Bishop matrix to determine the visual impact of wind turbines of up to 140 m in height, establishing that at distances <8 Km the impact is severe, at 8-16 Km, moderate, and for distances >16 Km the impact is slight.

Based on this data a table of Areas of Visual Influence was developed, according to the height of the facility (see Table 1), appropriate for wind farms with turbines of up to 5 MW and solar farms with solar tower of up to 206 m in height. Photovoltaic solar plants, as these are surface structures, have a smaller AVI than wind farms or solar concentrators, and thus have the lowest AVI on Table 1.

Table 1
Cultural Method Areas of Visual Influence (AVI) according to the height of the facility (wind turbines or solar towers)

Height of facility (m)	AVI* (Km)
41-48	16
53-57	19
72-78	24
90-100	30
100-140	48
140-182	54
182-206	61

**Area of Visual Influence*

3.2 Preparation of the digital elevation models

In order to carry out the visibility study of the RE facility it is necessary to prepare a digital map of the area of study, to be followed by an analysis with the SIG tools, in this case ArcGIS 10.5.

The digital mapping of the area can also be created using 3D point-cloud obtained with LIDAR or, with modification, in raster format, with Digital Terrain Models (DTM) adding Digital Surface Models (DSM) which include the height of the elements obtained with an “Final DSM” raster with all the required heights. Although the 3D point-cloud obtained with LIDAR is more precise, this was not used in the present study due to the weight of this data and lesser compatibility. Rather, DTM and DSM in raster format was used, permitting the creation of individual cartography of the areas of study at the scale 1:25.000.

The various DTMs included in the AVI of the facility were obtained from the CNIG (*Centro Nacional de Información Geográfica*) and files of contour lines were obtained as *shapefiles* from the National Topographical Database (*Base Topográfica Nacional)* 1:25.000 (BTN25) for the AVI, converted into an DTM raster using ArcGIS. The result serves as a base to which will be added the various DSM rasters. In the Cultural Method, vegetation, edifications and the installations rasters.

To obtain the DSM of vegetation, data was sourced from the Spanish National Forestry Map (*Mapa Forestal de España*) at the scale 1:50.000 (MFE50). For the DSM of buildings and installations, data was gathered from the shapefiles of buildings and installations from the BTN25.

Given that the focus of this research is the visual impact on the landscape in the vicinity of cultural heritage sites, it is necessary to map all protected areas within the area of study, as well as the cultural heritage sites themselves, where present, and all the ZPCO: active observation points, such as viewpoint or scenic routes (tourist routes, scenic roads, etc); passive observation points, such as visual corridors (roads, highways, etc); or the rest of the ZPCO, especially those with a permanent and high concentration of observers. Each of these elements are mapped and the appropriate height assigned to each.

To assign heights in the ArcGIS to the shapefiles without them two new fields must be created in the table of attributes of each shapefile, these will be called “levels” and “height”. These fields will be “double”, with precision 0 and scale 0. In the “levels” field, the number of levels of each type of edification is entered. In the “height” field, the heights of the edifications are entered, calculated using the “field calculator” as the product of the field “levels” by 3 units.

Once the necessary data is obtained and the corresponding heights assigned to each shapefile, the DSM rasters are created. These DSM rasters are then added to the DTM in order to obtain the “Final DSM” raster used for subsequent analyses.

3.3 Analysis of the convergent visibility of the area of study

Convergent visibility is the visibility from outside the area of study towards the area of study itself. This is necessary to calculate the points from which the RE facility is visible, creating a map of these points. In the Cultural Method, the convergent visibility of both the RE facility and the cultural heritage site are calculated.

The analyses are conducted using ArcGIS 10.5, requiring a *shapefile* of each element of study (RE facility and cultural heritage site). These must be “point” or “Polyline” shapefiles. Polygon *shapefiles* must be converted to Polyline. A field called “OFFSETA”, a “short integer” type with a precision of 5, should be added to the table of attributes of the shapefile of RE facilities. This new field gives altitudes to the points and polylines of the shapefile. The height entered into this field depends on the type of facility and its location. In the case the facility is located in an area with vegetation, the height of the vegetation should be subtracted from this point. This field is not added to the shapefiles of the cultural heritage sites since these are included in the information on the height in the “Final DSM” raster

The viewsheds of the RE facility and the cultural heritage site are then calculated. For this, the “Final DSM” and, separately, the various shapefiles of the RE facility and the cultural heritage site were entered into the “viewshed” tool of ArcGIS. Thus, two rasters of the viewsheds are obtained, showing the points from which each construction can be seen. Then, the rasters are converted into polygons using the “raster to polygon” tool and the intersection of both viewsheds are calculated using the “intersect” tool. This provides a shapefile of viewsheds containing the areas from which both constructions can be seen at the same time. The resulting shapefile is superimposed on the previously obtained map with all protected areas, cultural heritage sites and the various ZPCOs of the AVI. In this way, a map is obtained of all the ZPCO from which both constructions are visible.

A shapefile is then created of the significant, sensitive points of each ZPCO from which both constructions can theoretically be seen. A map of viewsheds is created from each of these to determine what other features (benefits and attenuations) are visible from each ZPCO. From these significant, sensitive points an in-situ verification must be made to verify both constructions can be seen and for taking the photographs for the survey and an analysis of the visual contrast is conducted. With the completion of the field work, the real points at which both constructions can in fact be seen are checked and a new shapefile is created designating each point correlatively as ZPCO01, ZPCO02, etc.

Finally, superimposed on the “Final DSM” raster are the shapefiles of 1) the viewsheds from which both constructions are visible, 2) the real significant, sensitive points of each ZPCO and 3) those contained within the protected area, the cultural heritage sites, all the ZPCO and any other significant element for analysis (benefits or attenuations). Thus, a map of all the ZPCO from which both constructions are visible is obtained, including the possible benefits and attenuations of the landscape.

3.4 Analysis of visual quality

The visual quality of the landscape in the vicinity of the cultural heritage site was subsequently calculated from each ZPCO. Visual quality is measured according to 1) the intrinsic importance of the cultural heritage site, 2) the cultural or acquired importance and 3) possible benefits or attenuations.

3.4.1 Intrinsic importance of the cultural heritage site (I_i)

The assessment of the intrinsic importance (I_i) of a cultural heritage site consists of four categories, according to a location's objective international, national, regional or local importance. Due to the significance of cultural heritage, the intrinsic importance is calculated on the basis of 3 points using the evaluation scale indicated in Table 2

Table based on the scale developed by Grijota [30] and adapted for the purposes of this research.

Table 2
Intrinsic importance of the cultural heritage site (I_i) (Source: [30])

Type Cultural Heritage Site	Description	I_i*
International Interest	Elements declared by UNESCO as World Heritage Sites. Touristic routes of international interest. Specific sites of global popularity such as museums or individual architectural elements.	12
National Interest	Sites of declared cultural interest under the Law 16/1985, of June 25, on Spanish Cultural Heritage (complexes, monuments, etc). Scenic or touristic routes of national interest.	9
Regional Interest	Sites of declared cultural interest within autonomous communities. Scenic or touristic routes of regional interest.	6
Local Interest	Locations or scenic viewpoints of local or county interest, such as chapels, shrines, parks, etc.	3

***** *Intrinsic importance*

3.4.2 Cultural or acquired importance of the cultural heritage site (I_c)

The intrinsic importance of the cultural heritage site is weighted based on the literary and artistic references to the site, its importance to popular cultural in the area and through surveys of the population of each ZPCO (this is particularly important for local heritage sites with less intrinsic value and less legal protection). In this way the cultural or acquired importance of a cultural heritage site is determined. The results are weighted using Equation 1. Table 3 shows the values from 0 to 3 given to each variable of cultural importance according to the relevance of the site.

$$I_c = I_i + I_{cal} + I_{caa} + I_{cpz} + I_{cezpco} \quad \text{(Eq. 1)}$$

Where:

I_c: is the cultural or acquired importance of the site.
I_i: is the intrinsic importance of the cultural heritage site.
I_{cal}: is the cultural importance due to references in literature of the cultural heritage site.
I_{caa}: is the cultural importance due to the artistic representations of the cultural heritage site.
I_{cpz}: is the cultural importance in the popular culture of the area.
I_{cezpco}: is the cultural importance according to surveys of ZPCO with urban centres.

Table 3
Cultural Method Acquired importance of the cultural heritage site (I_c)

Degree of acquired importance	Description	Cultural importance of each variable (I_{cal}, I_{caa}, I_{cpz}, I_{cezpco})
Zero importance	a) No mentions in literature. b) No appearances in art. c) No importance to local popular culture. d) Surveys give zero points for importance to popular culture in the area of the cultural heritage site.	0
Moderate importance	a) There is a mention in literature. b) There is appearance in art. c) It has moderate importance in local popular culture. d) Surveys give one point for importance to popular culture in the area of the cultural heritage site.	1
Significant importance	a) There are at least two mentions in literature. b) There are at least two appearances in art. c) It has significant importance to local popular culture. d) Surveys give two points for importance to popular culture in the area of the cultural heritage site.	2
Very significant importance	a) There are more than two mentions in literature. b) There are more than two appearances in art. c) It has a great deal of importance to local popular culture. d) Surveys give three points for importance to popular culture in the area of the cultural heritage site.	3

3.4.3 Intrinsic importance of each ZPCO (I_{zpco})

Each ZPCO from which both sites can be seen has an intrinsic importance that is added the cultural importance of the cultural heritage site itself.

The evaluation of the intrinsic importance of each ZPCO (I_{zpco}) is conducted based on their classification according to the attitude of the observer. Those in which the observer has an active and positive attitude in their perception of the landscape and the cultural heritage site (viewpoint or scenic route) are considered of high value, scoring 3 points. Those in which the observer has a passive attitude in their perception of the landscape in their travel or displacement (visual corridors) are considered of low value, scoring 1 point. Those in which there is a high concentration of observers with easy access and without a predetermined attitude, but for whom the landscape is a part of their daily visual experience (rest of ZPCO, as urban centres) are considered of medium value, scoring 2 points.
The Cultural Method introduces a distinction also between four categories within each type of ZPCO, on a rising scale, established, as with the intrinsic importance of the cultural heritage site, according to objective values depending on their importance. This evaluation scale was adapted in Table 4 based on the scale developed by Grijota [30].

Table 4
Intrinsic importance of each ZPCO (I_{zpco}) (Source: [30])

Type of ZPCO*	Importance of the ZPCO	Description	I_{zpco}**
Scenic viewpoint	International Interest	Elements declared by UNESCO as World Heritage Sites or Biosphere Reserves and other specific elements of global popularity such as museums or individual architectural elements, Biosphere Reserves, touristic routes of international interest.	12
	National Interest	Protected natural spaces under the Law 42/2007, December 13, on Natural Heritage and Biodiversity. Sites of declared cultural interest under the Law 16/1985, June 25, on Spanish Cultural Heritage (complexes, monuments, etc) Scenic or touristic routes of national interest.	9
	Regional Interest	Protected spaces under Community law. Red Natura 2000. Sites of declared cultural interest within autonomous communities. Scenic or touristic routes of regional interest	6
	Local Interest	Locations or scenic viewpoints of local or county interest, such as chapels, shrines, parks, etc.	3
Visual corridors (except scenic routes)	Category 1	Highways and motorways.	4
	Category 2	National roads (Law 25/1988, July 29, on Roadways), basic, conventional regional roads and railway lines, including AVE and conventional rail.	3
	Category 3	County or local roads.	2
	Category 4	Rural routes and trails.	1
Rest of ZPCO	Category 1	Urban centres of more than 10,000 inhabitants	8
	Category 2	Populations of 1,000 – 10,000 inhabitants.	6
	Category 3	Population of less than 1,000 inhabitants.	4
	Category 4	Other points within the scope of the study.	2

** Zone of Potencial Concentration of Observers*
***Intrinsic Importance of each Zone of Potencial Concentration of Observers*

3.4.4 Benefits of the cultural heritage site from each ZPCO

In the Cultural Method the possible Benefits (B) offered to each ZPCO by the views of the cultural heritage site are evaluated. These Benefits refer to the Landscape Resources (LR), either natural (a rocky escarpment, a lake, etc.) or anthropological (a castle, a hermitage, a sculpture, etc.), that add value to the visual landscape of each ZPCO.

Table 5 provides a scale for the evaluation of the Benefits based on the existing Landscape Resources and the visual plane in which these are located according to the studies by Grijota [30].

Table 5
Evaluation of the Benefits: presence of Landscape Resources (LR)

Distance between the LR* and the ZPCO**	Benefits in each scenic field	Total Benefits (B_t)
Foreground (0-100 m)	$B_{p1} = \Sigma$ [nº LR x (+1.00)]	
Intermediate plane	$B_{p2} = \Sigma$ [nº LR x (+0.50)]	$\mathbf{B_t = B_{p1} + B_{p2} + B_{p3}}$
Background	$B_{p3} = \Sigma$ [nº LR x (+0.25)]	

**Landscape Resources*
***Zone of Potencial Concentration of Observers*

3.4.5 Attenuations of the cultural heritage site from each ZPCO

The possible attenuations (A) of the visual quality of the landscape from each ZPCO arise from the presence of Discordant Elements (DE) in the landscape or the existence of obstacles, noise or smells which diminish the view or enjoyment of the cultural heritage site. The Discordant Elements are anthropic elements which are poorly integrated or entirely unintegrated into the landscape (such as a highway or a facility) which diminish the visual quality of the landscape in the area. These attenuations of the landscape are subtracted from the value of the total cultural importance of the cultural heritage from each ZPCO.

Table 6 provides a scale for the evaluation of the attenuation of the visual quality of the landscape based on the number of Discordant Elements and the visual plane in which these are located according to the studies by Grijota [30].

Table 6
Evaluation of the Attenuations of visual quality

Attenuation variable	Partial attenuation	Total attenuation (A_t)
Existence of obstacles	A_{ob} = -1	
Existence of noise	A_{ru} = -1	
Existence bad smells	A_{ol} = -1	
DE in foreground (0-100 m)	$A_{p1} = \Sigma$ [nº LR x (-1.00)]	$\mathbf{A_t = A_{ob} + A_{ru} + A_{ol} + A_{p1} + A_{p2} + A_{p3}}$
DE in intermediate plane	$A_{p2} = \Sigma$ [nº LR x (-0.50)]	
DE in background	$A_{p3} = \Sigma$ [nº LR x (-0.25)]	

3.4.6 Total cultural importance of the cultural heritage site for each ZPCO (I_{CT})

The total score of these parameters for visual quality, calculated using Equation 2, indicates the total cultural importance of the cultural heritage site from each ZPCO (I_{ct}). Introducing this figure in Table 7 provides a qualitative value of the total cultural importance of the cultural heritage site for each ZPCO (I_{CT}) weighted using a 0.5 base scale for subsequent calculations.

$I_{ct} = I_c + I_{zpco} + B_t + A_t$ (Eq. 2)

Where:
I_{ct}: is the total cultural importance of each ZPCO.
I_c: is the cultural or acquired importance of the cultural heritage site.
I_{zpco}: is the intrinsic importance of each ZPCO.
B_t: is the total benefit from each ZPCO.
A_t: is the total attenuation from each ZPCO.

Table 7
Qualitative value of the total cultural importance for each ZPCO (I_{CT})

$\mathbf{I_{ct} = I_c + I_{zpco} + B_t + A_t}$	Qualitative value	Total cultural importance (I_{CT})
>20	Very high	3
16-20	High	2.5
10-15	Medium	2
5-9	Low	1.5
1-4	Very low	1

I_{ct}: is the total cultural importance of each ZPCO.
I_c: is the cultural or acquired importance of the cultural heritage site.
I_{zpco}: is the intrinsic importance of each ZPCO.
B_t: is the total benefit from each ZPCO.
A_t: is the total attenuation from each ZPCO.

3.5 Analysis of visual fragility

Subsequently, the visual fragility of the landscape in the vicinity of the cultural heritage site is analysed based on the visibility and accessibility of the RE facility from each ZPCO and the distance between the facility and each ZPCO.

3.5.1 Visibility of the RE facility from each ZPCO

The visibility of the RE facility from each ZPCO is evaluated based on the magnitude of the facility (number of turbines, surface area of the solar farm), its visual incidence and total contrast –consisting of the visual contrast, visual dominance and spatial dominance– of the facility on the landscape in the vicinity of the cultural heritage site subject to the study.

The magnitude (M_i) of the RE facility is evaluated using Table 8 according to the number of vertical installations or the surface area in hectares, depending on the type of facility. The table is based on the Spanish method developed by Hurtado [2] and field work of this research project into wind and solar farms [26].

Table 8
Magnitude (M_i) of the RE facility

Nº towers or turbines	M_i	Size of solar plant (Ha)	M_i
1-3	1.0	<3	1.0
4-10	1.3	3-10	1.3
11-20	1.5	10-20	1.5
21-30	1.8	20-50	1.8
>30	2.0	>50	2.0

Visual incidence (I_v) is evaluated according to the vertical and horizontal impact of the facility using equation 3, a modification of that proposed by Grijota [30] based on the experimental studies by Shang and Bishop [31] on the angle of visual impact.

$$I_v = 1+ [I_{vv} \cdot I_{vh}] = 1 + [(n + \sin \alpha) \cdot (n + \sin \beta)] \quad \text{(Eq. 3)}$$

Where:

- I_{vv}: is the vertical visual incidence.
- I_{vh}: is the horizontal visual incidence.
- α: is the angle of vertical visual incidence of the RE facility perceived by the observer. This is calculated on the vertical projection between the RE facility, taking the highest and lowest points, and the observer, considering the closest point to the project in the case the ZPCO is lineal or superficial.
- β: is the angle of horizontal visual incidence of the RE facility perceived by the observer. This is calculated on the horizontal projection between the RE and the observer, considering the closest point to the project in the case the ZPCO is lineal or superficial.
- n: is the number of quadrants. This is equal to zero if the angle is inferior to 90º, and one or more in the case the angle is superior to 90º.

In the case the angle of I_{vh} is greater than 90º, the value will be equal to the total sine of the angle of visual impact in the incomplete quadrant plus to nº of complete quadrants (n). In the case the angle is less than 90º, the value of I_{vh} will be equal to the sine of the angle of visual impact, in this case n = 0.

The total visual contrast (C_t) is evaluated according to the visual contrast (C_v), visual dominance (D_v) and spatial dominance (D_e), using Table 9 adapted from the *Visual Contrast Rating* (VCR) method by Smardon [32]. This is a very intuitive table for the in-situ evaluation of these concepts which requires the consultation of Smardon's study prior to application (given the extent of the study description of each concept is not exposed here).

Visual contrast (C_v) is the result of the sum of the scores for each contrast: colour, form, line, texture and scale. Visual dominance (D_v) refers to the importance of scale of the RE facility within the landscape.

Spatial dominance (D_e) is the evaluation of the placement of the RE facility in relation to the composition and position within the landscape and the scenic background.

Table 9
Adaptation of the *Visual Contrast Rating* [32] table for the present research

Visual Contrast (C_v)			**Visual dominance (D_v)**			**Spatial dominance (D_e)**				
	High	9								
Colour contrast	Medium	6	RE facility within a confined space							
	Low	3		Dominant	12			2-3x ratings Prominent	Dominant	6
	Nil	0				Composition	Prominent Significant Discreet			
	High	6								
Form contrast	Medium	4								
	Low	2	A part or entire RE facility within a confined space							
	Nil	0		Co-Dominant	8			1x rating Prominent or 2x ratings Significant	Co-Dominant	4
	High	3								
Line contrast	Medium	2				Position	Prominent Significant Discreet			
	Low	1								
	Nil	0	RE facility significant within the landscape							
	High	3		Subordinate	4			1x rating Significant	Subordinate	2
Texture contrast	Medium	2								
	Low	1								
	Nil	0				Background	Prominent Significant Discreet			
	High	6								
Scale contrast	Medium	4	RE facility small within the landscape	Insignificant	0			All ratings inconspicuous	Insignificant	0
	Low	2								
	Nil	0								
Σ Contrasts = C_v =				**D_v =**					**D_e =**	

The total visual contrast (C_t) is the sum of the visual contrast (C_v), visual dominance (D_v) and spatial dominance (D_e). The result is entered into Table 10 for a qualitative value of the total contrast (C_T) weighted using a 0.5 base scale for subsequent calculation.

Table 10
Cultural Method Qualitative value of Total Contrast (C_t)

$C_t = C_v + D_v + D_e$	**Qualitative value**	**Total Contrast (C_T)**
36-45	Severe	2.0
27-35	Significant	1.5
18-26	Moderate	1.0
9-17	Low	0.5
0-8	Insignificant	0.1

C_t: total visual contrast is the sum of
C_v: the visual contrast
D_v: visual dominance
D_e: spatial dominance

3.5.2 Accessibility of each ZPCO (Acc)

The accessibility of each ZPCO (A_{cc}) will be considered using an evaluation scale according to the type of ZPCO and, in the case of urban centres, according to population, has shown in Table 11 based on the studies by Grijota [30] and the “e” coefficient of Hurtado [2].

Table 11
Cultural Method Accessibility of each ZPCO

Type of ZPCO	Subtype	Accessibility (A_{cc})
Viewpoints and scenic routes	-	2.00
Inhabitants	>10.000 hab.	2.00
	>5.000 hab.	1.90
	>300 hab.	1.70
	>150 hab.	1.50
	>100 hab.	1.30
	>50 hab.	1.20
	>25 hab.	1.10
	>0 hab.	1.05
	0 hab.	1.00
Visual corridors	-	1.00

3.5.3 Qualitative classification of the Distance between each ZPCO and the RE facility (D)

The qualitative classification of the Distance between each ZPCO and the RE facility (D) will be evaluated using the Diego-Chías matrix (Table 12). In the case of vertical installations, an extrapolation of the Sinclair-Thomas Matrix was used [28]. For surface installations, the classification is based on calculations made during field work.

Table 12
Diego-Chías matrix of qualitative classification of the Distance (D) between ZPCO and the RE facility

Level of impact	Class Qual. (D)	Height towers or turbines (m)							Solar plant surface (Ha)				
		41-45	52-57	70-78	90-100	100-140	140-182	182-206	<3	3-10	10-20	20-50	>50
		Range distances (km)							Range distances (km)				
High	**2.00**	0-2	0-2.5	0-3	0-4	0-5.5	0-7	0-8	0-0.3	0-0.5	0-1	0-2.5	0-3
Medium-	**1.50**	2-4	2.5-5	3-6	4-8	5.5-11	7-14	8-16	0.3-0.5	0.5-0.9	1-1.8	2.5-4.5	3-5
Medium	**1.00**	4-6	5-8	6-10	8-13	11-18	14-23	16-26	0.5-0.7	0.9-1.3	1.8-2.6	4.5-6.5	5-7
Slight-	**0.75**	6-9	8-11	10-14	13-18	18-25	23-32	26-37	0.7-0.9	1.3-1.7	2.6-3.4	6.5-8.5	7-9
Slight	**0.50**	9-13	11-15	14-18	18-23	25-32	32-41	37-47	0.9-1.1	1.7-2.2	3.4-4.4	8.5-11	9-12
Almost nil	**0.25**	13-16	15-19	18-23	23-30	32-42	41-54	47-61	1.1-1.4	2.2-2.8	4.4-5.6	11-14	12-15
Nil	**0.1**	>16	>19	>23	>30	>42	>54	>61	>1.4	>2.8	>5.6	>14	>15

3.6 Partial visual impact from each ZPCO

The partial visual impact from each ZPCO refers to the visual impact of RE facilities on the landscape in the vicinity of a cultural heritage site in each ZPCO. This is measured using equation 4 which incorporates all the parameters indicated:

$$I_{vp} = I_{ct} \cdot M_i \cdot I_v \cdot C_T \cdot A_{cc} \cdot D \qquad \text{(Eq. 4)}$$

3.7 Partial visual impact from each ZPCO weighted by survey

Once the partial visual impact for each ZPCO has been determined, the results are weighted using a survey of the local population in each ZPCO (Fig. 2).

Survey design

For conducting the survey, images are presented one beside the other following Shang and Bishop's method [31]. A significant image of each ZPCO is used. One of the images should be the original view of the landscape and the other a photomontage of the same view with the future RE facility. Given the horizontal nature of these facilities, it is recommended that images be presented one over the other, that is, the modified landscape above and the original landscape below. (Fig. 3). These images are presented to participants before beginning the questionnaire with a brief explanation of what they will see in a digital format, either on a screen or printed A4-A3 photographs.

Survey explores five aspects through Likert-type scales: *Participant sociodemographic data, Effect on visual appearance, Effect on the visual perception, RE facilities' integration in the Cultural Landscape* and *Importance of the heritage site in the popular culture* (Fig. 2).

1-Sex: (M – W) **2-¿Age?** **3- level of Studies** (L-M-H) **4-Resident of the Area?** (Yes–No–Seasonal) **Survey Code:**

Placing the respondent on the topic	**Yes**	**No**
5 Look at these pairs of photographs, do you find any difference between the two views of the landscapes?		

Effect on the visual appearance of the landscape (Rate from 0 to 3; 0 = nothing and 3 = a lot)	**0**	**1**	**2**	**3**
6 In your opinion, how much does the installation modify these views of the landscape?				

Effect on the visual perception of the landscape (Rate from -3 to 3 depending on how you consider it is a negative or positive effect)	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
7 In your opinion, how much do you prefer these views with the installation?							

RE facilities' integration in the Cultural Landscape (Rate from 0 to 3; 0 = nothing and 3 = a lot)	**0**	**1**	**2**	**3**
8 Do you think that wind power facilities are well integrated into the landscape and its surroundings?				
9 Do you think that the photovoltaic facility is well integrated into the landscape and its surroundings?				

Importance of the heritage site in the popular culture (Rate from 0 to 3; 0 = nothing and 3 = a lot)	**0**	**1**	**2**	**3**
10 How important do you think the *Monastery and Castle of Uclés* is in the popular culture of the area?				
11 How important do you think the *PA of Segóbriga* in the popular culture of the area?				

Fig. 2. Cultural Method Survey of the ZPCO inhabitants

Fig. 3. Example of the images shown in the survey

Survey's weighting procedure

For analysis purpose only *Effect on visual appearance* (question 6) and *Effect on the visual perception* (questions 7) are considered. Question 6 is coded from 1 (nothing) to 4 (very much). As the aim is assessing *negative* visual impact of the RE facilities, scores of -3, -2 and -1 in question 7 are coded as 4, 3, 2 respectively whereas scores from 0 to 3 are coded as 1 (which means no negative visual impact). Both mean scores are used to calculate a Total mean score. Result is rounded to the nearest whole number (1, 2, 3 and 4) which corresponds to the qualitative values of visual impact "slight", "moderate", "severe" or "high", respectively. Entering this impact level in Table 13 will provide a quantitative value for the parameter "E", which is subsequently multiplied, using equation 5, by the value of partial visual impact from each ZPCO (I_{vp}), result of equation 4, obtaining the partial visual impact from each ZPCO weighted by the survey results (I_{vpe}).

Table 13
Cultural Method weighting parameter according to survey (E)

Level of impact	Survey parameter (E)
High	1.50
Severe	1.25
Moderate	1.00
Slight	0.75

$I_{vpe} = I_{vp} \cdot E$ (Eq. 5)

3.8 Total visual impact of RE facilities on the landscape in the vicinity of cultural heritage sites

The total visual impact (I_{vt}) of RE facilities on the landscape in the vicinity of cultural heritage sites is determined calculating the media score of the partial visual impact from each ZPCO, weighted accordingly the survey using equation 6. The resulting value is introduced in Table 14 to produce a qualitative value for the total visual impact, based on the Spanish Environmental Impact Assessment Act which establishes four levels of visual impact: compatible, moderate, severe and critical.

$I_{vt} = \Sigma\, I_{vpe} / n^{o}\, ZPCO$ (Eq. 6)

Table 14
Cultural Method Qualitative values of the total visual impact of RE facilities

Value of I_{vt}*	Level of total visual impact
>10	Critical
(5-10]	Severe
(1.5-5]	Moderate
(0-1.5]	Compatible

***** *Total visual impact*

4. Discussion

The aim of this study was to describe a new methodology for the assessment of visual impact cause by renewable energy facilities on the landscape in cultural heritage sites which we called Cultural Method whose principal enrichment is the wide number of factors that are combined.

The Areas of Visual Influence that the Cultural Method proposed are considered correct based on the field work [26]. We showed that some 2 MW wind turbines were visible from distances greater than the AVI used in previous studies [1, 10, 14, 29].

The study of convergent visibility that the Cultural Method introduces, combines the visible area of the facility and that of the cultural heritage site, determining the area from which both landmarks can be seen enriching the existing methodologies which only contemplate one of the two aspects [2, 3, 5-7, 9-11, 14, 15, 22-24, 33, 34]. The Cultural Method requires considering two questions in selecting the ZPCO within the calculated area: a) it should be verified in situ that both landmarks are visible from the selected ZPCO as it is a theoretical calculation; b) in order for both landmarks to be observed from the same position these must form a horizontal angle of less than 60º to the observer in order for both to be within the field of vision at the same time.

When using the Cultural Method, the analysis of the visual quality of the landscape implies the assessment of different factors (intrinsic and cultural importance of the cultural heritage site, intrinsic importance of each ZPCO, benefits and attenuations of the cultural heritage site from each ZPCO) that never before were considered for a visual impact assessment [2-5, 7-9, 11, 12, 15, 22, 23, 27, 29, 33, 35-38]. Such complete analysis of visual quality allows obtaining a total cultural importance of the cultural heritage site from each ZPCO. The use of the evaluation scale for the intrinsic cultural importance of the cultural heritage site proposed by Grijota [30] is considered appropriate, as this permits a rapid evaluation of the site in terms of its protection and degree of importance. The concept of total cultural importance of the heritage site from each ZPCO, and each of the visual quality parameters are considered appropriate in identifying and defining the landscape as a sum of cultural elements [39] which project the character of a society on a territory and thus reveal, semiotically, the culture of the society which produced it [40]. The weighting scale of the qualitative value of the total cultural importance from each ZPCO is considered appropriate for the objectives of the study as it permits the landscape of the local environment to receive a high qualification based on a series of cultural values, thus reflecting the value that local inhabitants assign to their environment [39].

As a difference from existing methodologies, the Cultural Method introduces the analysis of visual fragility by taking into account three basic concepts: visibility, accessibility and distance from a novel perspective.

The visibility of a RE facility is defined by the product of magnitude, visual incidence and contrast. Previous methodologies [2-5, 7-9, 11, 12, 15, 22, 23, 27, 29, 33, 35-38] do not include the magnitude of the RE facility as it is defined in the Cultural Method. With this methodology both wind farms with more than 3 turbines and sold power plants larger than 3 Ha. are penalised. In general, references to sold power plants are difficult to be found. For the purpose of visual incidence, Grijota original equation [30] has the limitation of obtaining values lower than one when large distances are considered, which diminish visual impact value. However, when using the Cultural Method, equation 3 provides values for visual incidence closed to one unit when the RE facility is far from the ZPCO as the facility barely alters the viewshed, and close to two units when the RE facility is close to the ZPCO. Regarding contrast, existing methodologies usually include colour and/or size, but not as detailed by Smardon. The Cultural Method adapts the Visual Contrast Rating table (see Table 9) [32] weighting the obtained results by the total qualitative contrast (see Table 10) which assures a better adjustment of the obtained visual impact value.

The great strength of the Cultural Method against previous methodologies [2-5, 7-9, 11, 12, 15, 22, 23, 27, 29, 33, 35-38] is that it lends a value for the accessibility according to the type of ZPCO (viewpoints, inhabitants, and visual corridors) (see Table 11): In the case of viewpoints or scenic routes the value of the accessibility could duplicate the visual impact value due to its cultural importance, in the case of populated ZPCO or inhabitants, accessibility is evaluated in terms of the number of inhabitants; and in the case of visual corridor ZPCO, accessibility does not modify the resulting visual impact of the RE facility given its lesser cultural importance.

In terms of distance as a factor of visual fragility, the Cultural Method provides the Diego-Chías matrix of qualitative classification of distance between the RE facility and the ZPCO which takes into account modern wind farms higher than 100 m. and solar power plants according to its area which makes a difference with previous methodologies [2, 3, 10, 14, 27, 28, 41].

By calculating the product of the values of these different factors, the Cultural Method provides a partial visual impact from each ZPCO (Eq. 4). This equation is considered to contribute with results more representative of human manner of perceiving visual impact of RE facility in the landscape conceived as a sum of cultural elements [39], a reality in which all factors play a role, not additively but interrelatedly where the value of one impacts the results of the others.

Following the Aarhus Convention, the Charter of Krakow, the ELC and numerous studies [16-19, 42], the Cultural Method introduce the parameter "E" for weighting public opinion in evaluating the visual impact of these types of facilities (see Eq. 5).

Calculating the media score of the partial visual impact from each ZPCO, weighted accordingly the survey (Eq. 6.) the total visual impact is obtained which finally allows to obtain the qualitative value of total visual impact adapted to the Spanish Environmental Impact Assessment Act.

5. Conclusion

The Cultural Method is a methodology for general application, including on-shore and off-shore wind farms, FV and solar concentrator plants and any other type of installation which may have a visual impact on the landscape. The total visual impact is modified according to the different classifications set out in the Environmental Impact Assessment Act of Spain.

During the course of the research project, various parameters of the methodology were verified [26], confirming that these are coherent with the public perception of the visual impact of wind and solar power facilities.

The application of Cultural Method to the case studies [26] certified that it is important to incorporate within the evaluation of heritage sites cultural concepts such as the number of literary and artistic references, the importance of the heritage site to local popular culture and surveys of local inhabitants. This research found that by incorporating these concepts local cultural heritage sites can benefit from a more realistic evaluation in visual impact studies than that strictly provided by law.

The great strength of the Cultural Method is the inclusion of public opinion into the calculation allowing the visual impact of these facilities to be weighted accordingly. This complies with the directives of the ELC, the Charter of Krakow and other treaties which assign a fundamental role to public perception of environmental impact on local landscapes.

This methodology will allow public administrations to carry out their own studies and assessments of the visual impact of RE facilities in the vicinity of their cultural heritage sites, thus favouring the protection, management and regulation of territories in accordance with the ELC.

The scope of this methodology is very broad: it may be applied to EIA as a methodology for the study of the visual impact of RE facilities on cultural heritage sites and the landscape; it can also reduce costs for energy companies, applied in planning stages to determine if a facility is appropriate to the site while serving as a tool for local municipalities to contrast the studies presented on the environmental impact of RE facilities on their local landscape.

Credit author statement

Jesús C. Diego: conceptualisation, investigation, methodology, project administration, resources, survey, formal analysis, data curation, field work, software, writing of the original draft, visualization and publication. Saray Bonete: survey, field work, statistical analysis of the survey data and writing review. Pilar Chías: conceptualisation, project administration, supervision, funding acquisition and revision of the final draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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