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Long-distance and Cross-border Electric Power System Interconnections: Strategic needs, Sustainability, Environmental and Social Issues

POWER LINES AND THE PUBLIC PERCEPTION

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SUMMARY

The interconnections between electrical systems are a "technical and economic need" in order to facilitate the use and optimization of the energy sources and to improve the supply guarantee. At the same time, transmission lines are the most extended works of the electrical networks, having to carefully analyze their design and line routes since some serious impacts and/or conflicts can be caused or increased due to their location.

The space occupancy and the visual perturbation are primary factors of overhead line impact in the environment. On the other hand, the electric (E) and magnetic (B) fields produced by electrical installations have become of great concern to the population, provided their possible link with health aspects.

From the environmental point of view, the implantation of a new electrical infrastructure constitutes an intrusion in the landscape that may give rise to a decrease in the quality of the landscape of the location where it is inserted. Such visual impact is directly related with visibility level of the new shape introduced in the land and with the contrast between this and the original landscape.

It is possible to assess the capacity of a landscape to absorb certain modifications, minimizing the alterations in the visual qualities that the viewer perceives.

This paper shows the procedures followed in local cases where analysis of levels of electrical and magnetic fields and of visual landscapes has been incorporated to electrical project planning and works of electrical projects of 500 kV in AC and ±600 kV in DC.

KEYWORDS

Visual Impact, Magnetic Field, Electric Field, Environmental Issues.

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1. Methodology

The methodology of applied evaluation considers the use of simulation tools for the calculation of fields E and B. For the case of visual impact, the methodology is based on the use of indicators and informatics tools of the territorial analysis, which follows the guidelines stated in the normative frame in force and the parameters proposed worldwide regarding landscape.

For the calculation of electromagnetic fields, the methodology used consisted of carrying out simulations by means of a software, used at international level. This requires the elaboration of a tridimensional model for each analyzed case. As to the magnetic fields, the method of direct integration is used for the calculation; and for the electric field the finite elements method was used.

The measurement procedures of electric and magnetic fields produced by lines and installations of industrial frequency are described in standards IEEE 644-1994 [1] and IEC 61786:1998 [2]. The fields calculated in the present work follow the standard recommendations for three axes meters. For determining B_R and E_R in the simulations, first the efficient values of each one of the three spatial components (x, y, z) which define the field must be calculated.

Apart from considering the levels of electric and magnetic fields, it is necessary to analyze the alterations introduced to the landscape by HV towers and to assess the visual impact caused by each considered alternative.

In order to establish the current landscape conditions of the involved area, and to obtain its quality and visual absorption capacity for receiving new installations, some indicators were used such as the magnitude or total **visibility** grade of the studied area (M_{VA}) which corresponds to the land portion with visual access, and the visual quality of the **context** subjected to visual intrusion (QV).

For the visibility calculation, the first step was the choice and ranking of the observation points (VP). These were taken in relation to routs, roads and use areas of the influence zone. The detected observers were grouped according to their interests and features to rank their relevance for this analysis in function of amount of observers, reason of journey or stay and the observation time.

From the observation points, the visible areas were determined by means of a Geographic Information System (GIS). It was used a digital model of elevations, which included land heights, buildings and medium and large groves for recreating the spatial reality of the sector. The initial visibility or visual basins obtained (VA) were later corrected considering the clarity loss by distance (PL) and they were weighted using a observer indicator (VP):

$$M_{VA} = VA \times PL \times VP \, , \qquad (1)$$

On the other hand, for the calculation of scene or visual quality (QV), homogeneous land units were identified within the studied area. Such units were defined by means of overlapping the following factors: physiographic features such as reliefs, materials, vegetation and presence of bodies or water flows, distinctive features of the scene as regards shapes, lines, textures and colors, and installed human activities. From the evaluation of the features defining each landscape unit, indexes were obtained in order to rank comparatively the landscape quality of all the units under study.

Finally, the results of the indicators analyzed in different stages of the methodological frame developed for obtaining the areas of greatest visual sensitivity in the case study were integrated. The concept of landscape visual sensitivity measures the possibility of incorporating foreign elements to it. Thus, it was determined a landscape sensitivity index (ISP) according to equation (2)

$$ISP = M_{VA} \times QV \qquad (2)$$

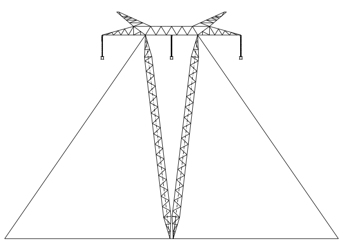
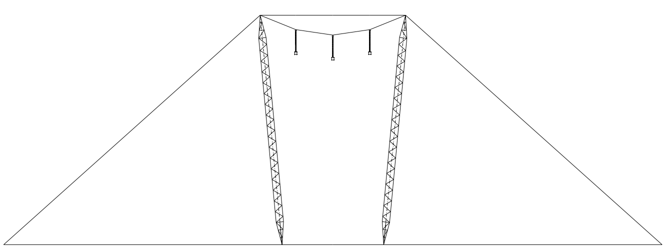
From the sensitivity indexes and their land representation, obtained in previous stages, it was assessed the capacity of visual absorption of the area for receiving the installation of assessed electrical infrastructure. Based on a landscape sensitivity map calculated in the base line study, the results were extrapolated to the different alternatives of analyzed designs for the electrical installation in order to obtain the **intensity** and location of the possible impacts (VI).

2. Considered cases

Two kinds of structures used in Argentina for lines 500 kV in AC were considered (Fig. 1,3 and 4) and it was considered a structure of 600 kV in DC, Fig. 2 and 5. It must be pointed out that nowadays in Argentina there are no DC transmission lines, the analyzed case corresponds to structures used in Itaipu system in Brazil.

Figure 1 - HVAC Towers 500 kV

Figure 2 - HVDC Tower 600 Kv

 Figure 3 - Typical Design Tower 500 kV	Typical Design (TD) Conductors height in towers: 33. 5 m Conductors height in mid span 10.8 m Tower height: 42.3 m Distance between external conductors: 26 m Right of Way: 79 m
 **Figure 4 -** Cross Rope Suspension 500 kV	Cross Rope (CR) Conductors height in towers: 33. 5 m Conductors height in mid span 10.8 m Tower height: 41.5 m Distance between external conductors: 14 m Right of Way: 67 m

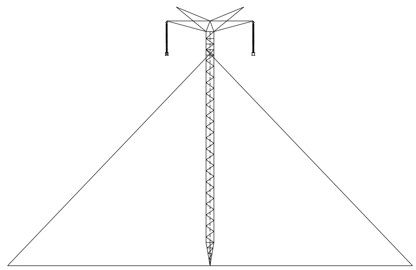


Figure 5 - HVDC CC 600 kV

HVDC

Conductors height in towers e: 37. 4 m

Conductors height in mid span: 10.8 m

Tower height: 46.0 m

Distance between external conductors: 15.4 m

For the analyzed cases of alternating current, it is considered that the current through the line is 1400 A which corresponds to a transmitted power of 1200 MW. For the case of HVDC current, it is also considered a current of 1400 A.

In order to apply the evaluation method of visual impact it was taken as example a study case that analyzed the installation of a high voltage line in a site that has a wide range of basic land situations. The influence area proposed for the draft generally is characterized by open spaces, with much vegetation and water flows, with the presence of parks and reserves. It represents a peculiar landscape within a metropolitan urban area living together with areas of strong anthropic mark, such as those devoted to the intensive rural use and more accurately, those of residential use of medium and high density, an active landfill and industrial plants.

3. Regulation in force

Low frequency electric and magnetic fields

The magnitudes of electric and magnetic fields of industrial frequency generated by installations of electrical companies must be below certain limits established in the regulations currently in force. Table 1 shows the limit values indicated by ICNIRP [3] and [4] and those taken in Argentina [5] and [6], for places of public access.

Table I – Maximum levels of electric and magnetic fields.

Magnitud	Maximum		
	ICNIRP [3]	ICNIRP [4]	Argentina [5] [6]
Electric Field [kV/m]	5	5	3(*)
Magnetic Field [μT]	100	200	25(*)

(*) The indicated limit values must be considered in the edge of the Right of Way (ROW) area and outside, at 1 m ground level.

Static fields

Regarding the exposure to static electric and magnetic fields generated by overhead lines, there is no regulation in Argentina imposing limits to the levels. However, some reference levels for the magnetic field are recommended by ICNIRP [7]; for the public in general the exposure level for any part of the body is 400 mT, it is also stated that for some people with electronic implants and implants having ferromagnetic materials the limit 0.5 mT should be adopted. For the case of electric field, ICNIRP has not recommended any exposure limits.

Visual impact

As regards visual impact, Res. SE 77/1998 [3] incorporates it within Environmental Parameters that must be compulsorily considered. The standard suggests a conceptual structure for evaluating the visual impact based on three important aspects: visibility, context and intensity.

Visibility provides a starting point for the evaluation, if there is no visibility there is no visual impact and further analyses would not be necessary. Provided that it is impossible to hide completely a high voltage line, it is necessary to set priorities that allow determining where such installations are visually appropriate or inappropriate, that is to say, which landscapes are particularly sensitive. One way of defining the sensitivity feature of a landscape is through definite factors such as: scene quality, land use or activity, number of viewers and existing installations.

Finally, it must be determined the visual intensity, through the study of specific features of the proposed installation. Besides, the impact study should include a test on the diverse alternatives that the current technology allows considering and should choose that having a better environmental profile.

4. Results

Electric Field

Fig. 6 shows the electric field profile for TD and Fig. 7 that corresponding to CR, considering the lowest height of conductors.

For the case of HVDC lines, these were not calculated in this work since there are neither imposed limits by national regulations nor limits recommended by ICNIRP.

The lowest values of the Electric field correspond to the CR structure, which corresponds to the case of the closest conductors.

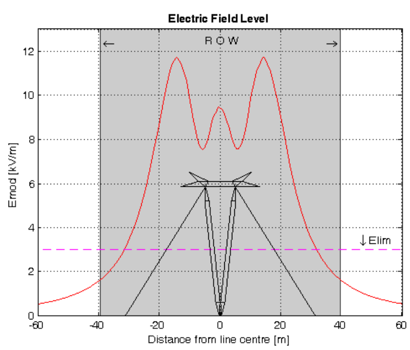


Figure 6 – Electric Field TD

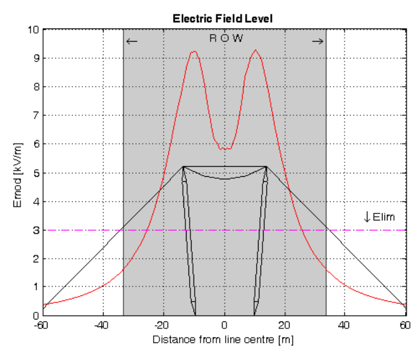


Figure 7 - Electric Field CR

Magnetic Field

Fig. 8 shows the field profile for TD and Fig. 9 that corresponding to CR. Additionally, Fig. 10 shows the Magnetic field profile for line 600 kV DC.

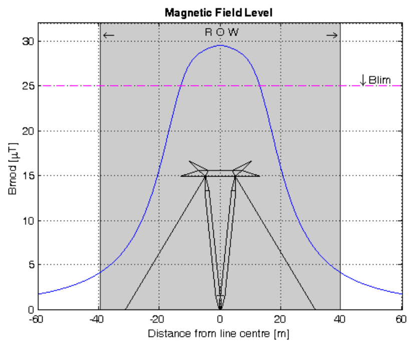


Figure 8 - Magnetic Field TD

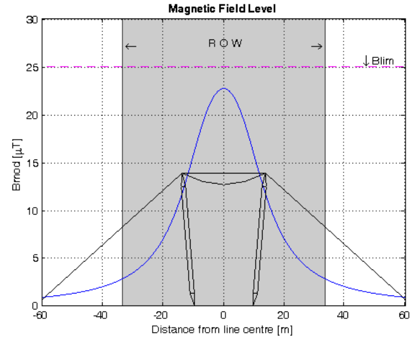


Figure 96 – Magnetic Field CR

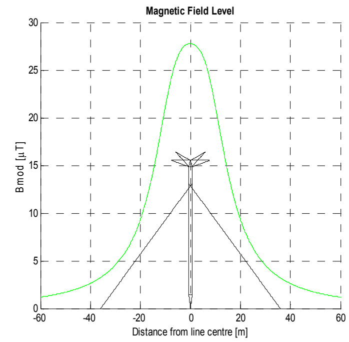


Figure 70 - Magnetic Field HVDC

The lowest values of the Magnetic field correspond to the structure CR, which corresponds to the case in which the conductors are closer to each other. Regarding alternating lines, all cases meet the limits established by Argentinean regulations.

For the case of line 600 kV DC, the values in all points are lower than those indicated by ICNIRP and correspond to the magnitude order of the land magnetic field.

Visual Impact

The sequence of procedures, for obtaining the impact intensity by the installation of new structures in the landscape, followed the above mentioned methodology. The evaluated indicators produced partial results that then were integrated for obtaining the conditions of context landscape sensitivity and thus forecasting the impact.

- **VP** indicator: Selection and ranking of observation points.

In order to obtain the indicator of potential observers (VP), these were classified into three groups: first, routes and roads, taking into account the average traffic, reasons for travelling and observation time; then, with other features, the populated centers, taking into account the number of residents, permanent or temporary, and their activities; and finally the visitors to parks and reserves in order to include the recreational and tourist activities, of high demand in quality landscape. In the analyzed case, from the performed calculation, it was determined that the residential areas, the park and reserve behave as high hierarchy observers.

- Indicator $\mathbf{M_{VA}}$: Calculation of magnitude or degree of total visibility of the area under study.

The calculation and mapping of the visibility (M_{VA}) of the area under study yielded as a result levels of higher exposure mainly associated to the observers of residential areas. This is due to the number of observers, their interests and stay and to their relative position on the land.

Fig. 11 shows as example the sequence of visibility calculation from these residential areas. Fig. 12 shows the "Map of total Visibility" of the area, considering the sum of the basins obtained for all the detected observation points. A decreasing scale from red, orange, green, blue represents the surfaces with greater visibility, grey represents the surface where there is no visibility. The points of greater visual exposure of the area under study are identified in the final map.

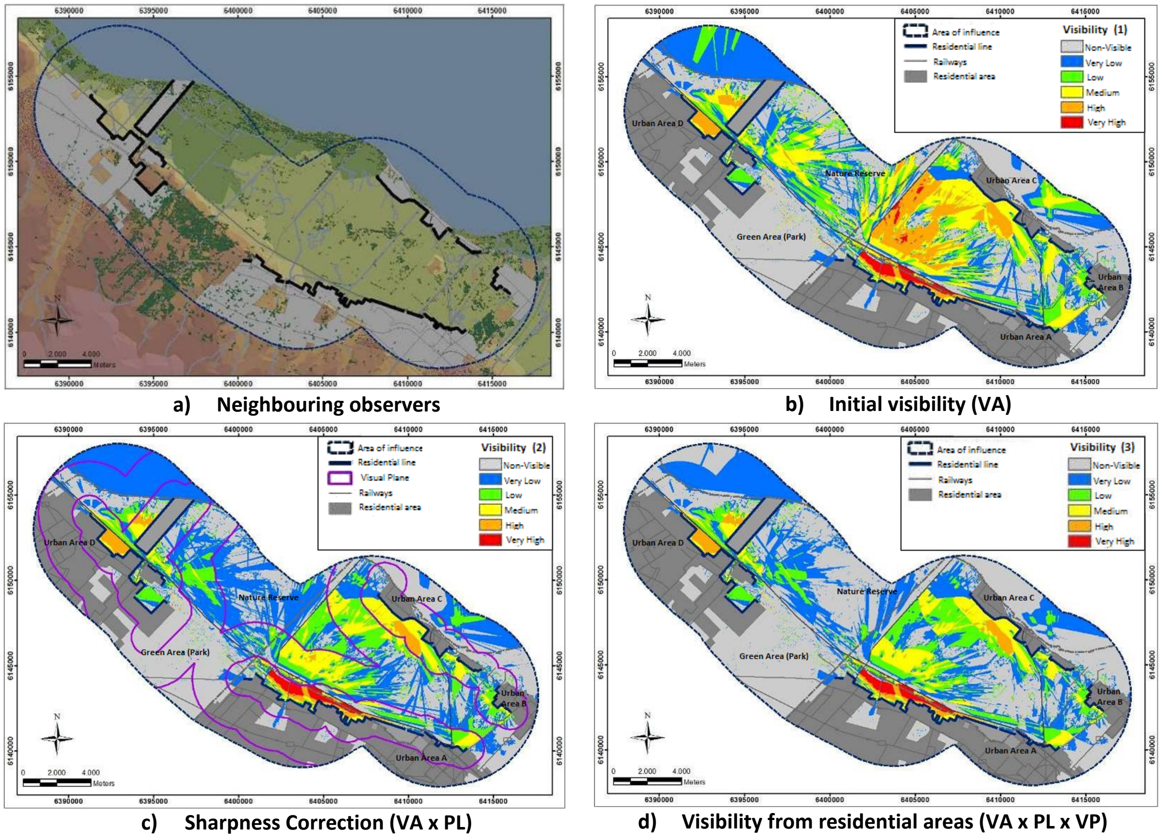


Figure 11- Secuencia de cálculo de visibilidad.

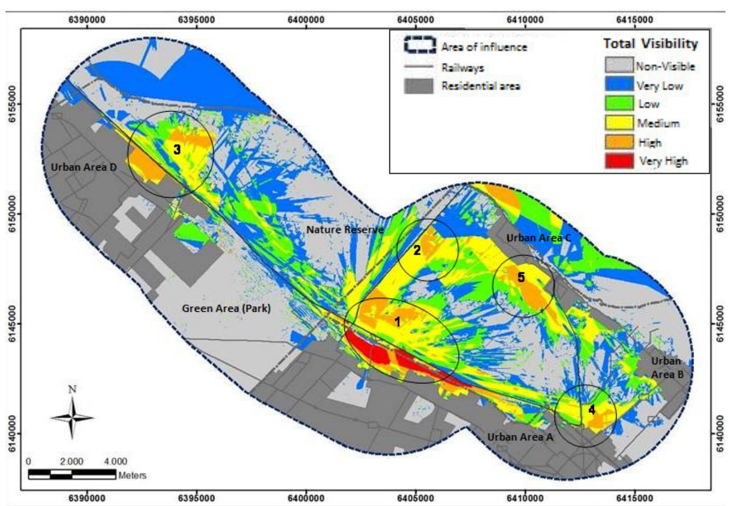


Figure 8 Visibility map of the area, from observation points detected.

- Indicator **QV**: Identification and ranking of the landscape units in the area under study.

Once the landscape units of the area under study were identified, the analysis and assessment of their features were carried out. Thus, the indexes of the scene or visual quality (QV) of each landscape unit were obtained.

Fig. 13 shows a map with the identified landscape Units, and Fig. 14 displays the map of the resulting visual quality. A decreasing scale from red, orange, yellow, green and blue represents the better-quality surfaces. For the units that obtained high quality values, the visual deterioration will be very high, whereas in the low quality units this deterioration will be insignificant.

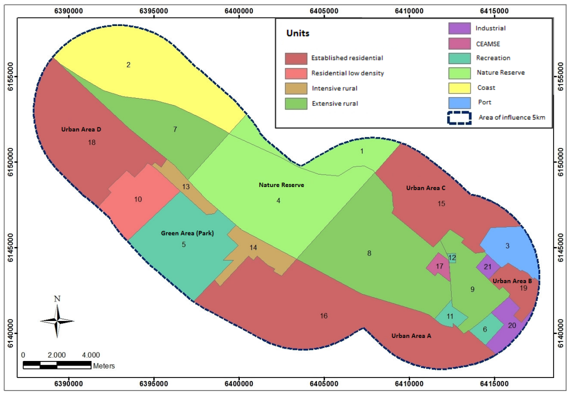


Figure 13 - Landscape units identified.

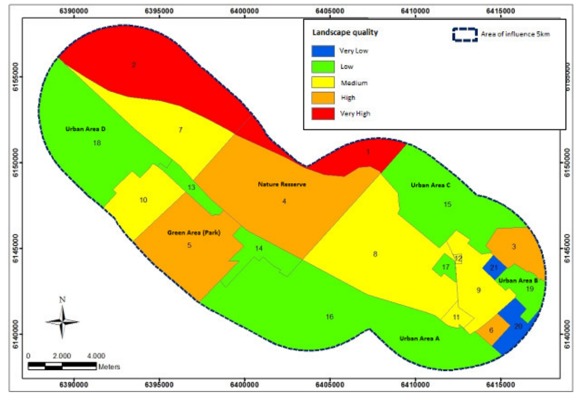


Figure 14 - Quality of Landscape map of landscape units.

- ISP: Landscape sensitivity index

Combining the visibility (M_{VA}) and landscape quality (QV) indexes of the studied area, the current areas with greater landscape sensitivity were obtained. Fig. 15 shows a decreasing scale from red to blue representing the surfaces with greater sensitivity and the points of greater landscape visual vulnerability were identified.

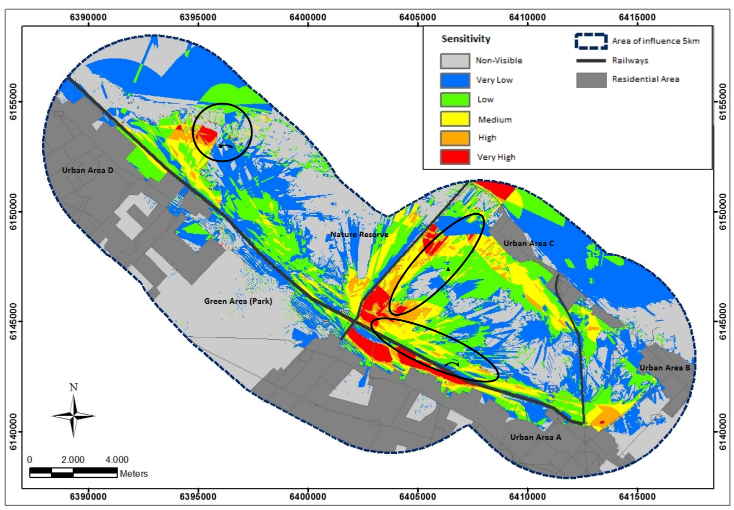


Figure 15 - Landscape sensibility Map.

- VI: Impact

Based on the calculated landscape sensitivity map in the base line study, the results were extrapolated to each alternative proposed design, in order to obtain the magnitude and location of possible impacts. These are shown in Fig. 16.

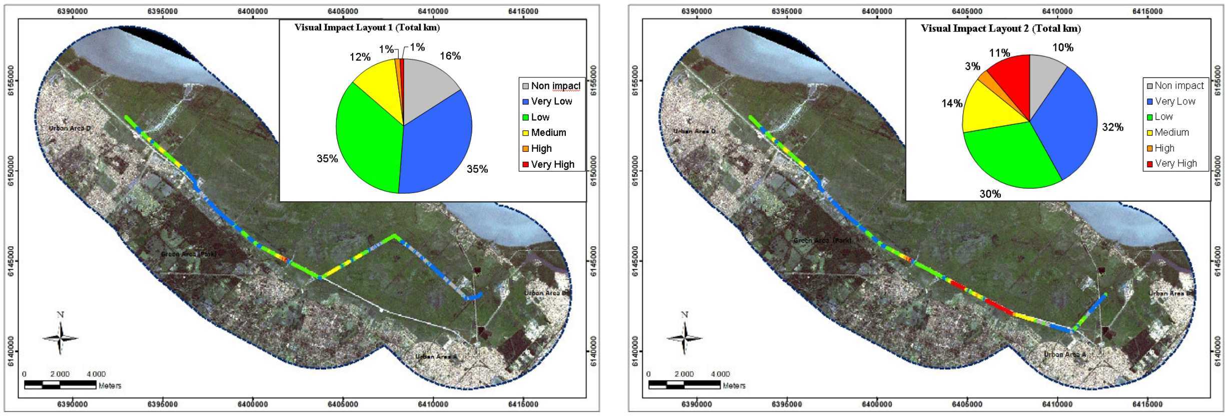


Figure 9 - Visual Impact for line route 1 and 2.

The results obtained in function of the performed analyses will support the decision-making about the design choice. For instance, in the presented cases, it is clearly observed an increase of medium and high impacts when getting closer to residential areas, orienting the decision to Design 1 whose impact is the lowest.

Generally, the greatest impact intensity of high voltage electrical installations over the environment will be associated to the towers. Whatever their shape or height, they will result in a visual alteration of the landscape, undermining the scene value of the physical expression where they are located. This loss in the visual quality value of the landscape will be translated, in general for the observer, into a high impact perception when the tower situation is in natural or rural media; into a degrading feeling when this is located in urban media destined to housing; and in industrial type sectors, its impact takes a neutral value since there is a greater acceptance to the tower location associated to industry; moreover for certain observers in rural media the tower presence is positive as they associate it with a prosperity signal.

Regarding the types of towers for the electrical installation in the definite design, some visual comparisons about those described in this work are carried out:

Tower	Visual Impact	Electric and Magnetic Fields
TD	More volume and density of the structure. More density of towers in the line route. More number of visual impact spots.	Higher levels of Electric and Magnetic fields. More distance between external phases and bigger right of way.
CR	Shorter towers, less visibility from long distances. More density of towers in the line route. More number of visual impact spots.	Lower levels of Electric and Magnetic fields. Compact design, smaller right of way.
HVDC	Less density of towers in the line route. Less number of visual impact spots. Higher towers, more visibility from long distances.	Towers with less numbers of conductors. There is no National regulation about Electric and Magnetic fields thresholds.

5. Conclusions

From the point of view of electric and magnetic fields, the best choice is that corresponding to tower CR, since the obtained values are lower for a same height on the land in the center of the opening, either under the tower or in the edge of the right of way strip. This is due to the fact that the conductors are arranged in a more compact way, i.e., closer to each other.

In Argentina, there are no exposure limits for static electromagnetic fields, but there is a reference indicated by ICNIRP where it is observed that the values produced by DC line, herein referred to, are much lower than the recommended limits. Also, it is noteworthy that the magnetic field values of DC line are of a magnitude order of the land magnetic field.

The procedures above mentioned allow characterizing the visual impacts taking into account the modification level of the initial natural conditions. It is noteworthy that if there are locations of electrical installations in areas of high landscape fragility and quality, the impact will be greater than in areas of low fragility and quality.

From the results, it is possible to take project decisions about the design of the electrical installation. Whatever the chosen design is, prevention, mitigation, maintenance and control measures must be considered in order to decrease, to the minimum, the visual impacts that the project will produce in the design, execution and operation stages.

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