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# Spatial distribution of an index of impact on solar and wind generation facilities based on meteorological phenomena

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**Abstract:**
Meteorological phenomena may have a positive or negative impact on solar and wind generating facilities. This work intends to build an impact index that comprises the frequency of occurrence of a set of phenomena, weighted each one according to expert's criteria, for 68 meteorological stations over Cuba and analyze the spatial distribution. The classification is given in five categories, ranging from "very unfavorable" to "very favorable". Overall it shows that phenomena under study have a greater incidence on solar than on wind facilities, since "clear skies", "thunderstorms" and "precipitation" have a strong impact, favorable or unfavorable according to the specific phenomenon. "Thunderstorms" are the most influencing phenomenon for wind facilities, with an unfavorable character. The spatial distribution shows favorable zones with regard to solar facilities in the provinces of Pinar del Río, Ciego de Ávila, Camaguey, the north coast of Las Tunas, Holguín and around the Gulf of Guacanayabo, and for wind generators at Pinar del Río, Artemisa, Ciego de Ávila, Camaguey, Las Tunas and the South coast of the Central and Eastern regions.

**Keywords:** meteorological phenomena, wind power generators protection, photovoltaic generators protection.

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## 1. Introduction

Meteorological phenomena may have a favorable or unfavorable impact on solar and wind energy generating facilities, so areas can be determined where their combined occurrence can contribute to the best and most efficient performance of the facility. From the project called "Study of the spatial location of electrical storms in Cuba and its trend" belonging to a Branch Program of the Environment Agency, where an updated spatial distribution of storms is obtained up to the year 2002 [1, 2], several studies are carried out on the annual cycle, regionalization, daily and inter annual cycles and spatial distribution [3-5]of several phenomena. These investigations, which involve the representativeness of all the meteorological phenomena that can be described by the current weather code registers, allow the results to be applied to the Sabana-Camagüey Archipelago [6-7] and to the Gibara wind development zone [8]. . Subsequently, with a new research project, the studies on phenomena are updated and improvements are made in the methodologies [9-15].

The purpose of this work is to develop an index of affectation by phenomena, calculated from the frequency of occurrence of the phenomena "clear skies", "smoke", "haze', "fog", "mist", "rain", "showers" and "thunderstorms" and a weight figure given to each of them, according to the criteria of specialists, for 68 meteorological stations in the country and then analyze the spatial distribution of the proposed index.

**2. Materials and methods**

The main source of information used in the present work was the current weather status code records from 68 stations throughout the country, whose spatial distribution was specified by Álvarez-Escudero and Borrajero [13]. For the study of the spatial distribution, the recommended period 1989-2010 in [16] was used, although due to the fact that both diurnal and nocturnal phenomena were being taken into account and that several stations did not have observations at night and early in the morning, a case by case analysis was made, readjusting the series to the period that had the most complete information. Whenever there were months with less than 95% completion within the series in use, the value of the variable that was calculated was replaced by the average of the value of the months surrounding the incomplete one [13-14]. Working with the selected periods allowed the percentages of useful information for all the series to range between 99 and 100%. The only stations with complete information in the period, where no rectifications had to be made were Bahía Honda (318) in the province of Artemisa, Casablanca (325) in the province of Havana and Camaguey (355) in the province of the same name. 97% of the stations had series of at least 5 years and 12 series worked with the maximum 22 years of the recommended period, only two stations Jagüey Grande (331) and Santiago de la Vegas (373) presented only two years of complete information due to to the fact that they were recently subjected to repairs and closures and in previous years they did not carry out observations at night and early in the morning. The data was taken from the New_THOR Database [16] implemented in MS-ACCESS for its management. The working variable is the frequency of occurrence of observations associated with certain phenomena, given as the number of observations referring to each phenomenon over the total number of valid observations. For the identification of the phenomena under study from the present weather code, the code values were taken, according to Table 4677, on "Current weather, communicated from a staffed meteorological station", from the Code Manual [ 17] and their identifications are shown in Table 1. The codes not represented in Table 1 refer to cases of very low or null occurrence for the study region.

**Table 1**. Meteorological phenomena used in the study and present weather codes associated to them.

| Phenomenon | Current weather code associated |
|---|---|
| Clear Sky | 00, 01, 02, 03 |
| Smoke | 04 |
| Haze | 05 |
| Fog | 10 |
| Mist | 11, 12, 28, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49 |
| Rain | 14, 15, 16, 21, 23, 24, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69 |
| Showers | 18, 25, 26, 27, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90 |
| Thunderstorm | 17, 29, 91, 92 , 95, 96, 97 , 99 |

In order to determine the relevance of the affectation that the different meteorological phenomena could have on the wind and solar facilities, a survey was carried out among knowledgeable personnel, which is summarized in Table 2.

**Table 2**. Form presented to collect the information from the survey to assess the impact that the different meteorological phenomena under study could have on wind and solar facilities.

| Phenomenon | PV Panels | | Wind Generators | |
|---|---|---|---|---|
| | Effect | Qualif | Effect | Qualif |
| Clear Sky | | | | |
| Smoke | | | | |
| Haze | | | | |
| Fog | | | | |
| Mist | | | | |
| Rain | | | | |
| Showers | | | | |
| Thunderstorm | | | | |

In Table 2, “Qualif” is a number between “-5” and “5” that gives a quantitative idea of how detrimental (maximum -5) or beneficial (maximum 5) the effect of the phenomenon may be on the equipment or facility. If the phenomenon does not cause any effect, its “qualif” is 0. “Effect” refers to the description of the impact on the equipment or facility caused by the phenomena under study. For the recognition of the phenomena among the respondents, the following definitions were used, taken in a general way from the World Meteorological Vocabulary [18].

- Clear skies: No cloud development or clouds dissipating or becoming less thick, sky without changes or clouds in formation.
- Smoke: Smoke is observed in the station or in its surroundings as a result of industrial activity, the burning of vegetation or other causes.
- Haze: Suspension in the atmosphere of extremely small dry particles, invisible to the naked eye and numerous enough to give the air an opalescent appearance.
- Fog: Suspension in the air of very small droplets of water, usually microscopic, which generally reduce horizontal visibility at the Earth's surface to less than one kilometer.
- Mist: Suspension in the air of very small droplets of water, usually microscopic, which generally reduce horizontal visibility at the Earth's surface to more than 1 km, but less than 5 km".
- Rain: Precipitation of water droplets from the clouds with a diameter greater than 0.5 millimeters, having different intensities. The rain-generating clouds are altostratus, nimbostratus, stratocumulus, cumulus and cumulonimbus.
- Showers:. Regularly strong short-term precipitation produced from convective clouds, beginning and ending abruptly with alternating cloudy and clear skies. Similar to downpours.
- Storm: Sudden discharge of atmospheric electricity manifested by a brief flash (lightning) and by a dry noise or a dull rumble (thunder). Storms are associated with convective clouds (cumulonimbus) and are usually accompanied by precipitation in the form of showers, rain or ice or sometimes snow, snow pellets, ice pellets or hail.

The solar and wind phenomena affectation index(PAI) is defined as:

$$PAI = P1 * \%\ Clear\ Skies + P2 * \%\ Smoke + P3 * \%\ Haze + P4 * \%\ Fog + P5 * \%\ Mist + P6 * \%\ Rain + P7 * \%\ Showers + P8 * \%\ Storms \quad (1)$$

where the coefficients from P1 to P8 given in (1) refer to the average among all respondents of the value of "Calif" for each of the phenomena under study and "% name of the phenomenon" refers to the percentage of occurrence of the phenomenon according to the climatic study of the current weather code reported at each station. 16 researchers and technicians from the National Cargo Office, INEL, Renewable Energies Directorate of the UNE and members of the projects "Spatial Distribution of Meteorological Phenomena in Cuba", "Solar Radiation Forecast in Cuba" and "Prognosis of Wind Potential in Cuba" all developed at the Institute of Meteorology and from project OP15 "Hazard, Vulnerability and Risk" of the Environment Agency, participated in the survey. The spatial distribution maps of the indexes was made, giving their values at each station, represented by circles whose radii are proportional to the ranges of magnitude of the affectation of the phenomenon in question. The categories or ranges of occurrence were five, identified as: "Very unfavorable", "Unfavorable", "Moderately favorable", "Favorable" and "Very favorable" and the corresponding numerical ranges are set from dividing the difference between the maximum and minimum value of the occurrence of the phenomenon in five approximately equivalent intervals and where the average value for all the stations is made to fall in the “Moderately favorable” range. The isolated cases where there may be extreme values of occurrence must be taken into account, so that they do not introduce bias in the design of the numerical value of the limits of the ranges.

**3. Results and discussion**

The result for the evaluation of the affectation to solar panels is summarized in Table 3. This Table shows that on average, all the phenomena are found unfavorable with the exception of "clear skies" that present a high positive index. With respect to unfavorable phenomena, the most damaging is the "storm".

**Table 3**. Result of the survey for the evaluation of the affectation to solar panels.

| Surveyed phenomena | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clear Sky | 5 | 5 | 5 | 5 | 5 | 5 | | | | 0 | 5 | 5 | 5 | 5 | 5 | | 4.6 |
| Smoke | 0 | -3 | 0 | -2 | -1 | -2 | | | | 0 | -5 | -1 | -3 | -3 | -2 | | -1.8 |
| Haze | 0 | -3 | 0 | -3 | -1 | -3 | | | | 0 | -4 | -1 | -3 | -3 | -2 | | -1.9 |
| Fog | 0 | -3 | -2 | -2 | -3 | -5 | | | | 0 | -4 | -5 | -3 | -1 | -2 | | -2.5 |
| Mist | 0 | -3 | -1 | -3 | -2 | -5 | | | | -1 | -3 | -5 | -3 | -1 | -2 | | -2.4 |
| Rain | -4 | -3 | -2 | -5 | -5 | -5 | | | | -4 | -4 | -5 | -2 | -1 | -2 | | -3.5 |
| Showers | -3 | | -2 | -4 | -5 | -3 | | | | -4 | -4 | -5 | -2 | -1 | -2 | | -3.2 |
| Thunderstorm | -5 | -5 | -5 | -5 | -5 | -5 | | | | -5 | -5 | -5 | -4 | -5 | -4 | | -4.8 |

In general, the effects exposed by the respondents reveal the fact that "clear skies" are very beneficial, "smoke", "mist", "fog", "rain" and "showers" can cause low generation by the presence of cloudiness or impediment of the arrival of direct radiation while "storms", in addition to the affectation by cloudiness can cause damage due to the occurrence of electric discharges. From the calculation of the PAI for each station, its spatial distribution is represented, as can be seen in fig. 1.

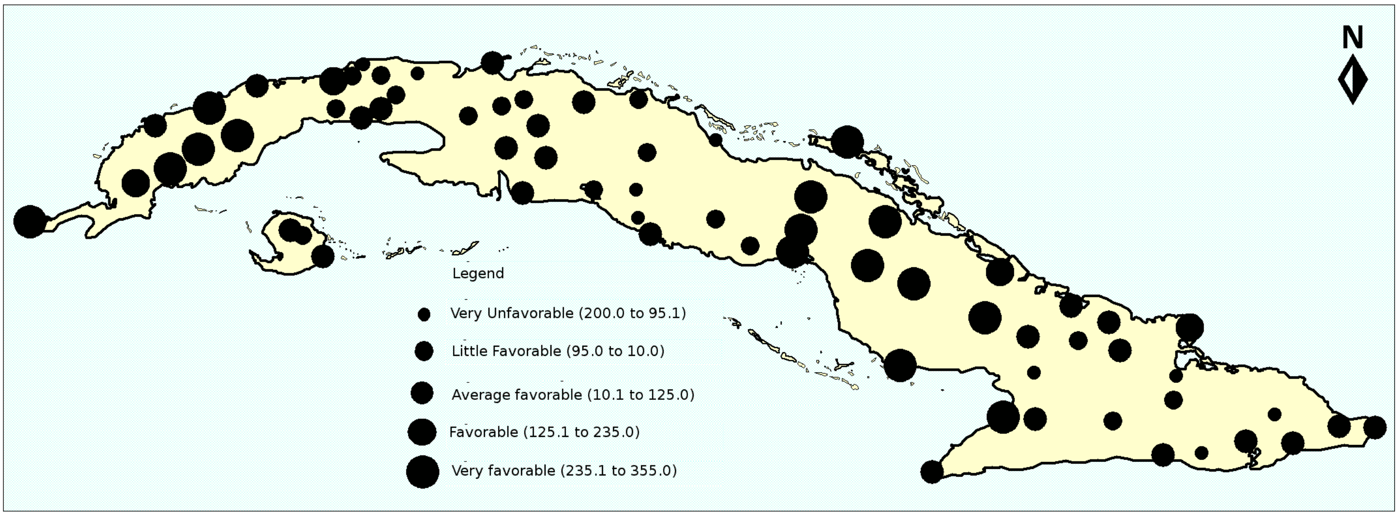


**Figure 1.** Spatial distribution of the PAI with respect to the solar energy production facilities for the Cuban territory.

The distribution shows indexes between -205.0 to 355.0, which covers a range of more than 500 values. The areas identified between "Favorable" and "Very favorable" are grouped in the provinces of Pinar del Río, Ciego de Ávila and Camagüey, the north coast of Las Tunas, the northwestern coast of Holguín and in areas around the Gulf of Guacanayabo, closely related to the high occurrence of observations with "clear skies" at those locations.

The results of the survey regarding the impact on wind turbines are presented in Table 4. Here the rates of impact by phenomena are lower than those calculated for solar energy installations, although they are generally unfavorable values more noticeable in the case of storms.

**Table 4**. Results of the survey to assess the affectation to aerogenerators.

| Surveyed phenomena | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clear Sky | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | -3 | | 0 |
| Smoke | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | | | -3 | | -0.3 |
| Haze | 0 | | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | | -3 | -3 | | -0.3 |
| Fog | 0 | | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | | -3 | -3 | | -0.5 |
| Mist | 0 | | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | | -3 | -3 | | -0.5 |
| Rain | 0 | -5 | -1 | | 1 | 1 | 0 | 0 | 0 | -1 | -1 | 0 | | 0 | 2 | | -0.3 |
| Showers | 0 | | -1 | 2 | 2 | 0 | 0 | 0 | 0 | -3 | -1 | 0 | | 0 | 3 | | 0.2 |
| Thunderstorm | -5 | -5 | -2 | -5 | -2 | -3 | -5 | -5 | -5 | -5 | -2 | -1 | -5 | -5 | -5 | | -4 |

The effects identified in the survey showed that "clear skies" caused greater heating and therefore increased convective movements and thus wind circulation, "fogs" and "mist" are indicative of low winds, "smoke" can imply dirt in the systems, "rain" and "showers" increase the wind flow, but they also increase the friction with the blades and "storms" cause a high impact due to electrical discharges.

The spatial distribution of the PAI for the case of wind turbines is presented in Fig. 2. Here the PAI ranges from -60.0 to 10.0 and its variation is much less marked than for solar energy facilities. The areas between "Favorable" and "Very favorable" are grouped in Pinar del Río, north coast of Artemisa, Havana and Mayabeque, Las Tunas and Holguín and the provinces of Ciego de Ávila and Camaguey as a whole. It should be noted that the Punta del Este station also has a "Favorable" index.

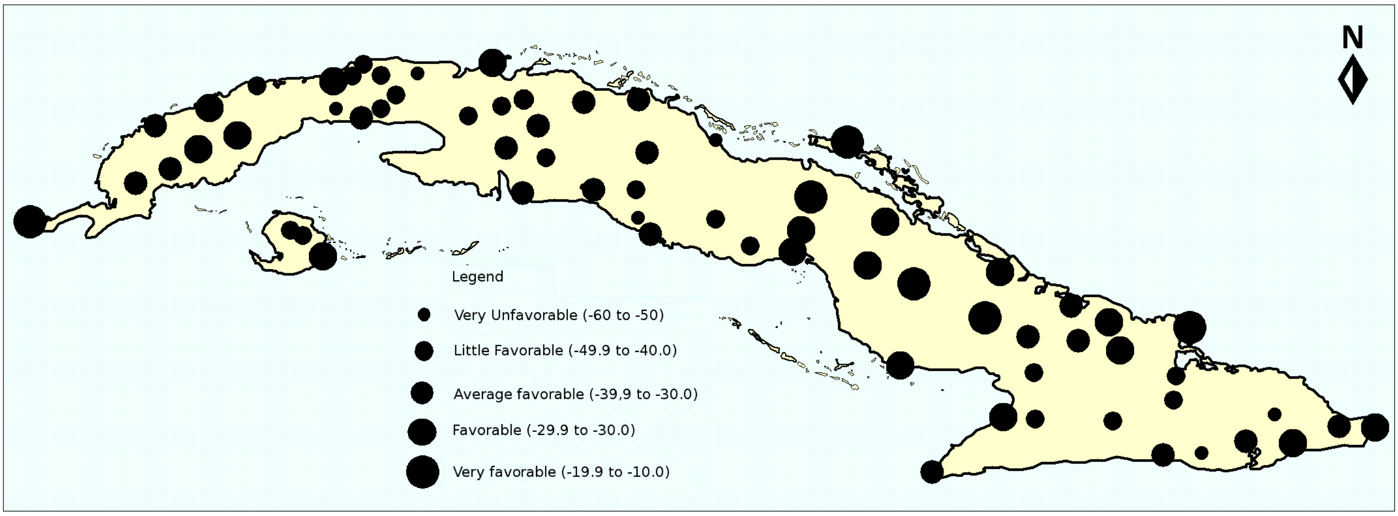


**Figure 2**. Spatial distribution of the PAI with respect to the wind turbines for the Cuban territory.

The Index of Affectation by Phenomena (PAI) can serve as another criterion to take into account when selecting an area for the installation of new solar and wind farms.

**4. Conclusions and recommendations**

The phenomena under study have a greater effect on solar generation facilities than on wind ones, since the effect of "clear skies", "storms" and "rain" stand out both favorably and unfavorably.

The fundamental affectation for wind facilities is an unfavorable one, due to "storms".

The spatial distribution of the PAI shows favorable areas for photovoltaic generation facilities in the provinces of Pinar del Río, Ciego de Ávila, Camaguey, the north coast of Las Tunas and Holguín and around the Gulf of Guacanayabo.

The spatial distribution shows favorable zones with respect to the occurrence of phenomena for the installation of wind turbines in Pinar del Río, Artemisa, Ciego de Ávila, Camaguey and Las Tunas.

It is recommended to increase the number of survey respondents and evaluate the changes that the Index of Affectation by Phenomena could present.

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