An Assessment Study of the Monthly Complementarity of Renewable Energy Resources in Colombia

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Abstract

In order to assess the feasibility of a combined use of renewable energy sources over a determined region, it is necessary to carry out complementarity studies. These studies let us know the generation profile of renewable energy sources, with high variability, over a specific interval of time and establish a possible match between two or more different energy sources. Such is the case of wind and solar energy sources. In this paper is presented an assessment study of the monthly complementarity of wind and solar resources over Colombia for electricity generation. It is proposed to assess the complementarity based on a novel approach, using a dataset obtained from high-resolution images of wind and solar monthly resource maps of Colombia; images previously treated using image processing techniques. Then, the dataset is used to calculate average energy generation on each month of the year, and the complementarity of both renewable resources is obtained calculating the degree of correlation between them, with the Pearson correlation coefficient. The obtained results show a good degree of complementarity between both energy sources in some regions of Colombia, at the different seasons of the year. The results obtained in this study can be useful to identify regions with high potential of installation of power generation plants based on wind and solar energy.

Keywords: complementarity study, image processing techniques, photovoltaic energy, wind energy.

1. Introduction

The constant growth of the world population and its development has led in a substantial increase in the demand of energy, most of it generated from fossil fuels, which contribute to the greenhouse effect and climate change (Roldán et al. 2014). To address this problem, the use of renewable energies for the electricity generation has increased, but their use is still limited in many countries, such is the case of Colombia (Cortés 2017).

Colombia is a country with a privileged condition in terms of renewable energy resources (RES), because of its location facing to the Caribbean Sea and the Pacific Ocean favors the generation of air currents, that can be used for the electricity generation through wind turbines (Edsand 2017); and its position in the Tropical Belt favors the capture of solar energy, that can be transformed into electrical energy using photovoltaic modules (Serrano 2017).

However, these RES do not generate a constant electrical power flow, because they are sources of a fluctuating nature, and changing according to the climate conditions. Therefore, arises the need of a combined use of both resources in order to achieve an optimal performance, complementing their electricity generation (Ospino-Castro et al. 2017).

Thus, complementarity studies are necessary to assess the feasibility of a combined use of wind and solar generation. For this purpose, high spatial and temporal resolution data obtained from measurements of weather stations are needed; and with this data the correlation between solar and wind resources is calculated.

In this paper is presented a complementarity study of wind and solar resources over Colombia for electricity generation. The complementarity is assessed based on a dataset obtained from high-resolution images of wind and solar monthly resource maps of the country. This is a novel approach, because these maps are generated with measurements obtained from weather stations installed across the country, and they are open access to the general public, while the measurements cannot be obtained so straight forward. The main disadvantage of the proposed procedure is that some accuracy is lost when the correlation is calculated, but it allows to know regions of the country with high degree of complementary between the RES throughout the year in an easier and faster way.

The rest of this paper is organized as follows: Section II presents the wind and solar resource maps from Colombia; Section III presents a procedure used for the complementarity calculation between both resources using image processing techniques; in the Section IV are presented the complementarity maps obtained using the proposed procedure; finally, Section V draws the main conclusions of this work.

2. Renewable energy monthly resource maps of Colombia

The IDEAM (which stand for Institute of Hydrology, Meteorology and Environmental Studies) together with the UPME (which stand for Mining and Energy Planning Unit), and with government support, have developed the wind and solar resource maps of Colombia. These maps are available to the whole society, with the special aim to be used by planners and decision makers in national and regional energy development programs and projects.

The most recent solar resource maps can be consulted at the following web site of the IDEAM (IDEAM-Solar 2018), while the wind resource maps at (IDEAM-Eólico 2018). For this study, it was downloaded the wind and solar resource maps reported in the web sites in the last year.

Solar resource maps

Figs. 1 to 3 show the solar resources maps of Colombia for the months of January to December. According with (Colombia 2015), these maps were created using an approximation of the spatial distribution of the solar resource, developed based on radiometric information measured directly in 71 stations over the country, complemented by 383 meteorological stations in where brightness measurements were registered, and 96 stations with measurements of relative humidity and temperature, variables that were correlated with the radiant intensity on the surface.

It can be seen from these maps that the global solar radiation over the country is around 2.5 to 7.0 kWh/m^2. Values above 5.0 kWh/m^2 are adequate for the installation of photovoltaic generation systems, especially in regions in the north of the country. The best month in terms of the solar resource is July and the worst is November.

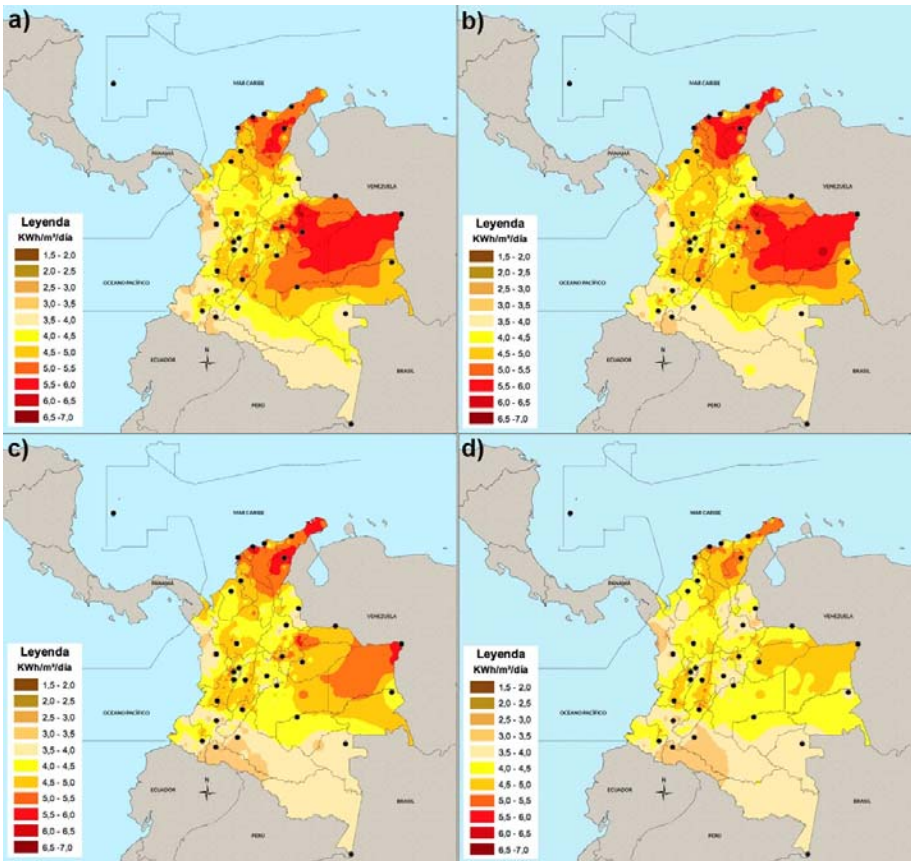

Fig. 1. Solar resource maps of Colombia: (a) January, (b) February, (c) March and (d) April.

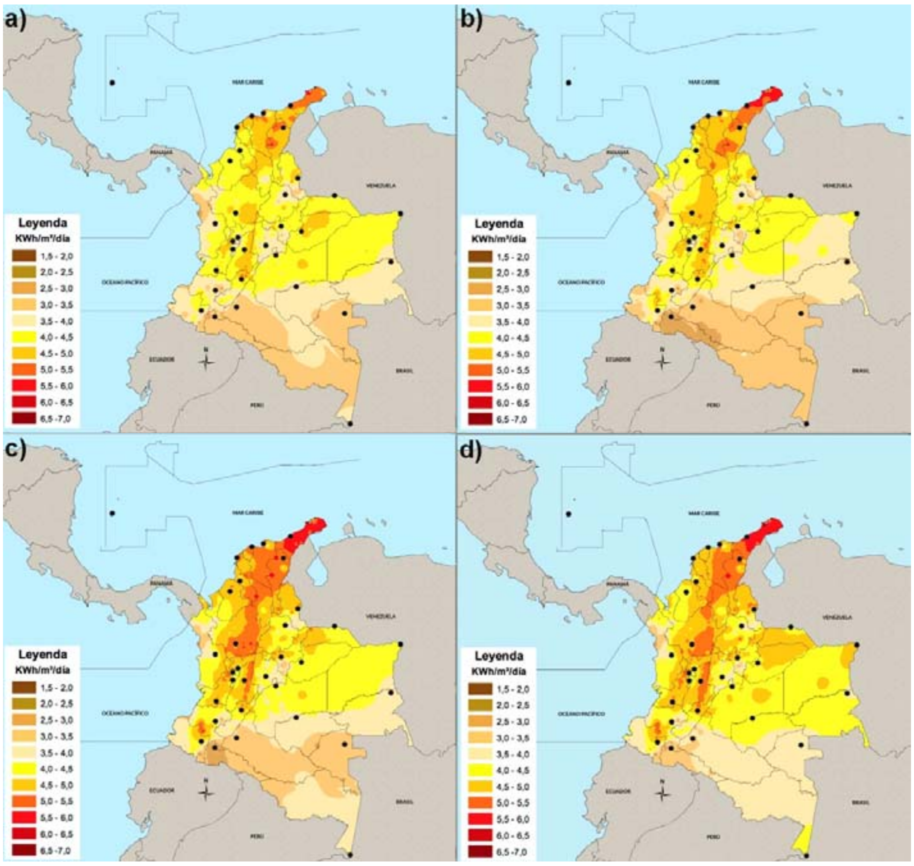

Fig. 2. Solar resource maps of Colombia: (a) May, (b) June, (c) July and (d) August.

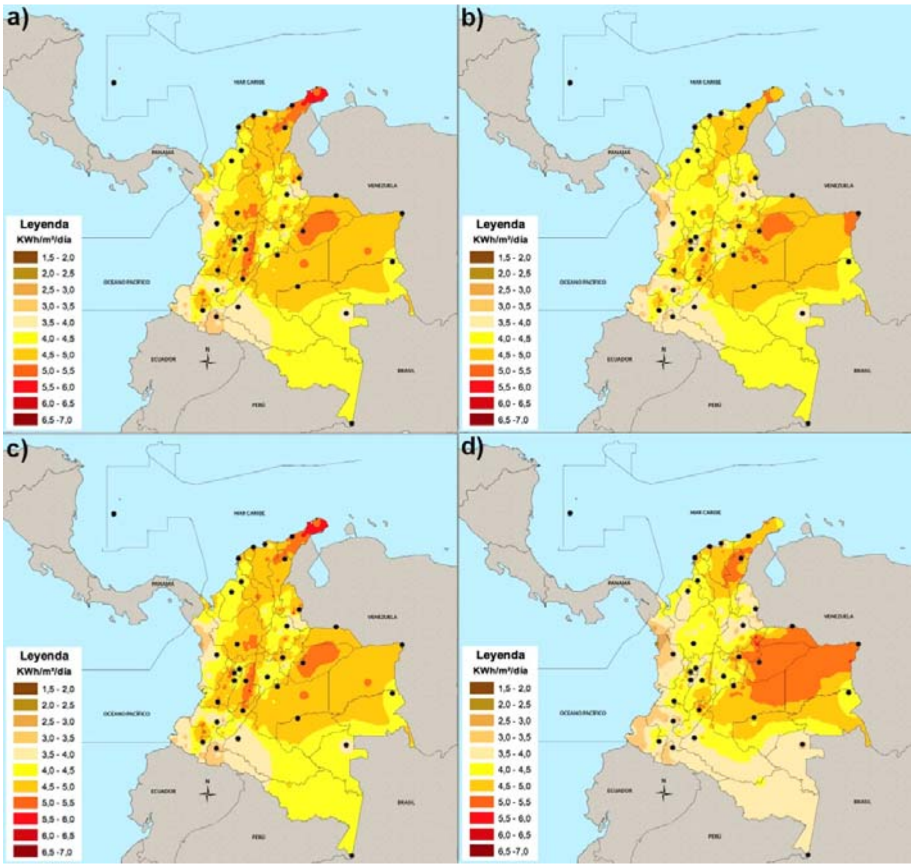

Fig. 3. Solar resource maps of Colombia: (a) September, (b) October, (c) November and (d) December.

Wind resource maps

On the other hand, Figs. 4 to 6 show the wind resource maps of Colombia for the months of January to December. The twelve maps contain the wind power density in W/m^2, at a height of 80 m. They were calculated using the average wind speed at the surface, interpolated at a resolution of 10 X 10 km, which represent an approximation of the spatial distribution of this meteorological variable over the Colombian territory. These maps were obtained with physics-based algorithms that use regional meteorological models, together with data from anemographs taken directly from 111 stations in the country and complemented with information from low-resolution meteorological models at 122 grid points (Colombia 2015).

The wind resource maps show a wind power density with values between 0 and 1728, values that correspond to wind speeds around 0 to 11 m/s. High capacity wind turbines (above 2 MW) are designed to operate at their rate capacity at a wind speed of between 12 and 16 m/s, so it is possible to intuit that wind turbines of low capacity are suitable for their installation in specific regions of Colombia, but further studies need to be conducted in order to probe this statement.

Also, the information contained in these maps is expressed in units of wind power density (W/m^2). Thus, it is necessary convert the information to the same units of the solar resource maps.

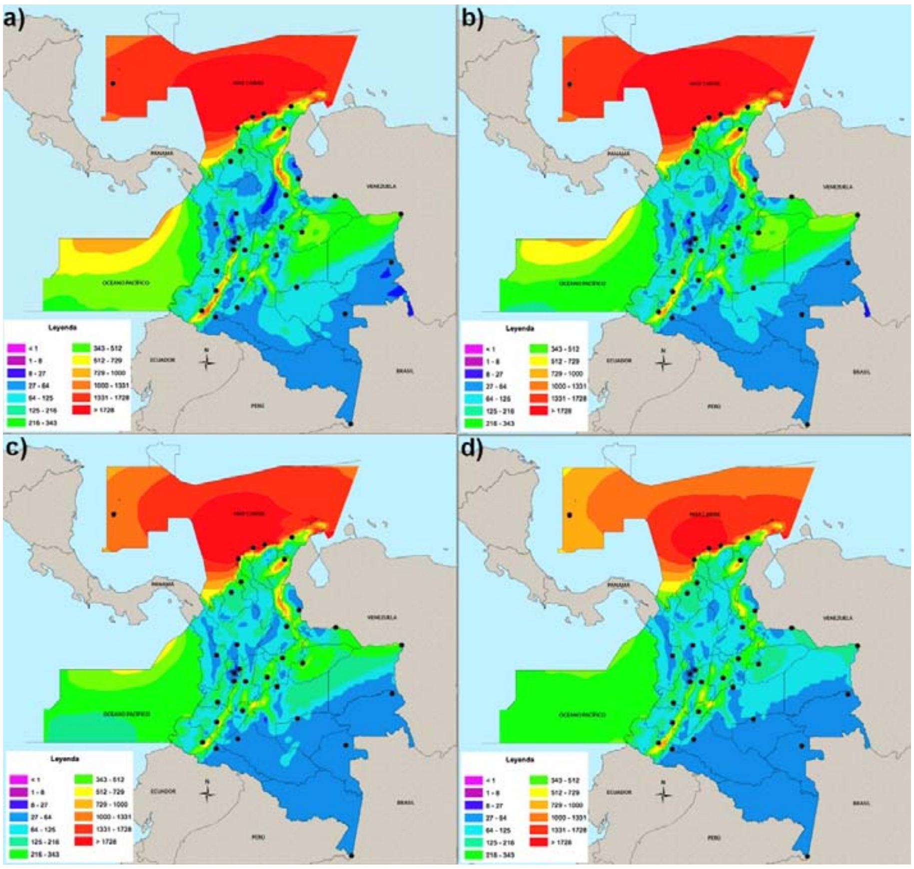

Fig. 4. Wind resource maps of Colombia: (a) January, (b) February, (c) March and (d) April.

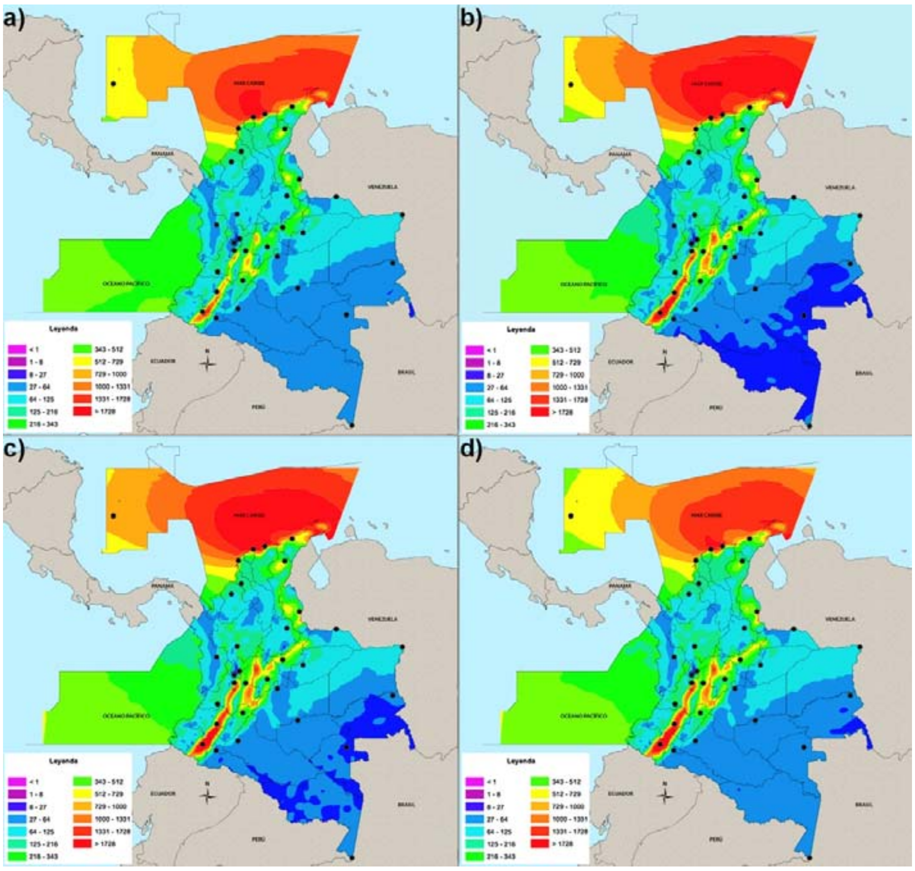

Fig. 5. Wind resource maps of Colombia: (a) May, (b) June, (c) July and (d) August.

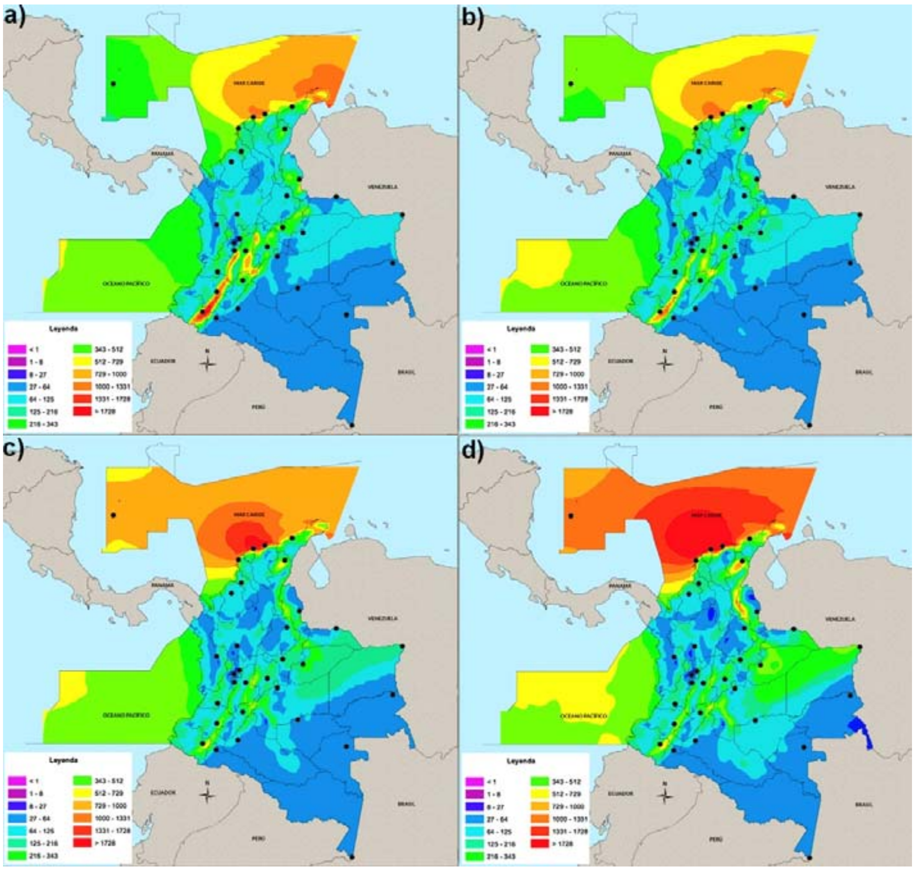

Fig. 6. Wind resource maps of Colombia: (a) September, (b) October, (c) November and (d) December.

3. Assessment of the complementarity of RES

The complementarity existing between solar and wind renewable energy resources can be obtained by calculating the degree of correlation between them. The Pearson correlation coefficient is a measure of the statistical relationship, or association, between two continuous variables. It is based on the method of covariance. It has values between -1 to +1, where a positive value indicates that there is a higher potential for the combined used of both renewable sources, and a negative value indicates that neither renewable source is recommended to be used because of their low resource.

The Pearson correlation coefficient $R(x, y)$ of a (x, y) point of the RES map can be calculated as (Miglietta 2017)

$$R(x,y) = \frac{\sigma_{M,WS}}{\sqrt{\sigma_{M,W}\,\sigma_{M,S}}} \tag{1}$$

where σ is the covariance, and M, S and W stand for month, solar data and wind data, respectively. The covariance for the twelve months is:

$$\sigma_{M,S} = \sum_{M=1}^{12}[S_M(x,y) - S(x,y)]^2 \tag{2}$$

$$\sigma_{M,W} = \sum_{M=1}^{12} [W_M(x,y) - W(x,y)]^2 \tag{3}$$

To be able to apply the equations previously shown, it is necessary extract the data from the resource maps. Each pixel of each map represents a value in terms of the resource available at specific site. If high-resolution images are used, the accuracy of the values obtained in the process of extraction of the data is better. For this purpose, image processing techniques can be used. The OpenCV library was used for the image processing of the maps because it is a free library, widely used.

A procedure for the data extraction based on image processing techniques was proposed in (Vega-Sánchez et al. 2017) and improved in this study, because in this case was used a RGB (RED, Green, and Blue) scale, while in the previously reported contribution was used a gray scale. The use of a RGB scale improves the accuracy of proposed procedure, but it makes a little bit complex the data management.

The flow diagram of the proposed procedure to extract the data from the renewable resource maps and to assess the complementarity is shown in the Fig. 7.

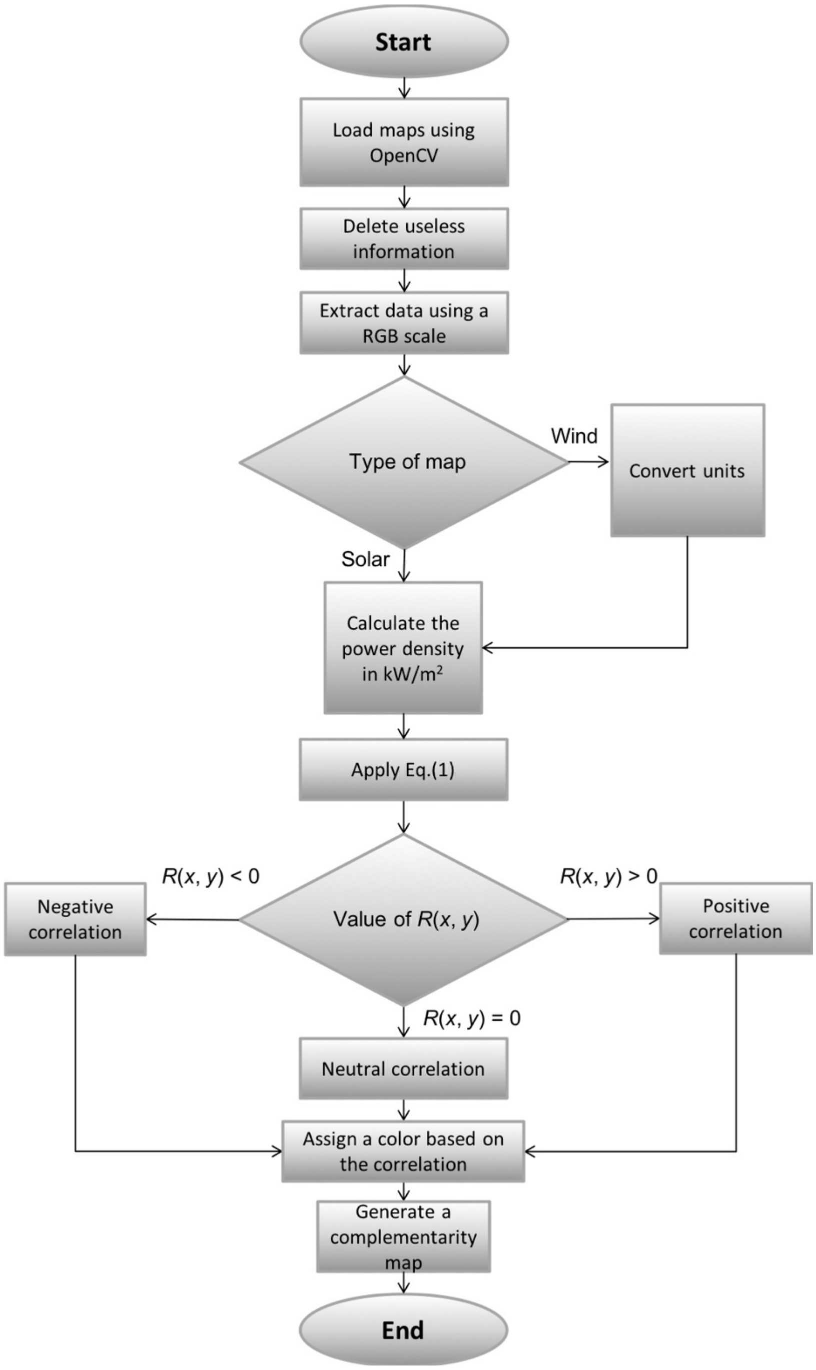

Fig. 7. Flow diagram of the procedure proposed to assess the complementarity of RES.

The first step is load the images of wind and solar resource maps using the OpenCV library. Then, it is deleted the information that is not useful for the study, e.g. other countries, the sea, etc.

After that, the information contained in the maps is processed by sweeping through all the pixels on the maps, decomposing each pixel in values on the RGB scale, and storing the information in matrices. Three matrices for each pixel are needed, one for red color, other for the green, and other for the blue.

The next step is to calculate the average power density that can be obtained on each month. This unifies the units, because the solar resource is given in kWh/m^2, while the wind resource is given in m/s. This process is called normalization of the data and allows to apply Eq. (1). Thus, it is obtained the Pearson correlation coefficient for each pixel, in each month of the year.

Finally, a scale of colors is defined based on a range of values varying from +1 to -1 and a new set of maps that show the complementarity between wind and solar resources for each month are generated.

4. Monthly complementarity maps obtained

Applying the proposed process, a complementarity map for each month was obtained. Figs. 8 to 10 show the monthly complementarity maps obtained. The scale used varies from blue to yellow colors, where the yellow corresponds to high values of complementarity, and a blue color the worst complementarity. From these figures, it can be seen that the zones in the northeast of the country have the higher complementarity, that means, these are zones suitable for the combined used of solar and wind systems. While in the south, the complementarity is the lowest. This behavior can be explained due the influence of the available resource, that is, according with the renewable resource maps, the worst solar potential resource is in the south, the same happens with the wind potential. Also, it can be seen that the months of September and October have the lowest values in terms of complementarity, so these months can be selected as critical months in the process of design or selecting the generation systems.

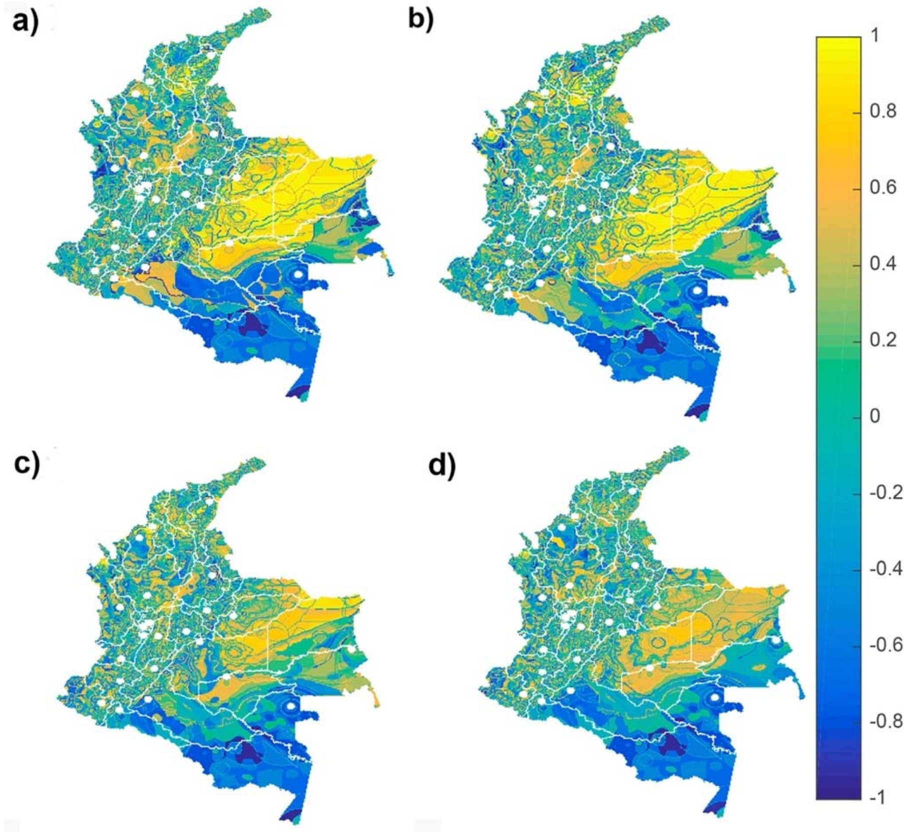

Fig. 8. Complementarity maps of Colombia: (a) January, (b) February, (c) March and (d) April.

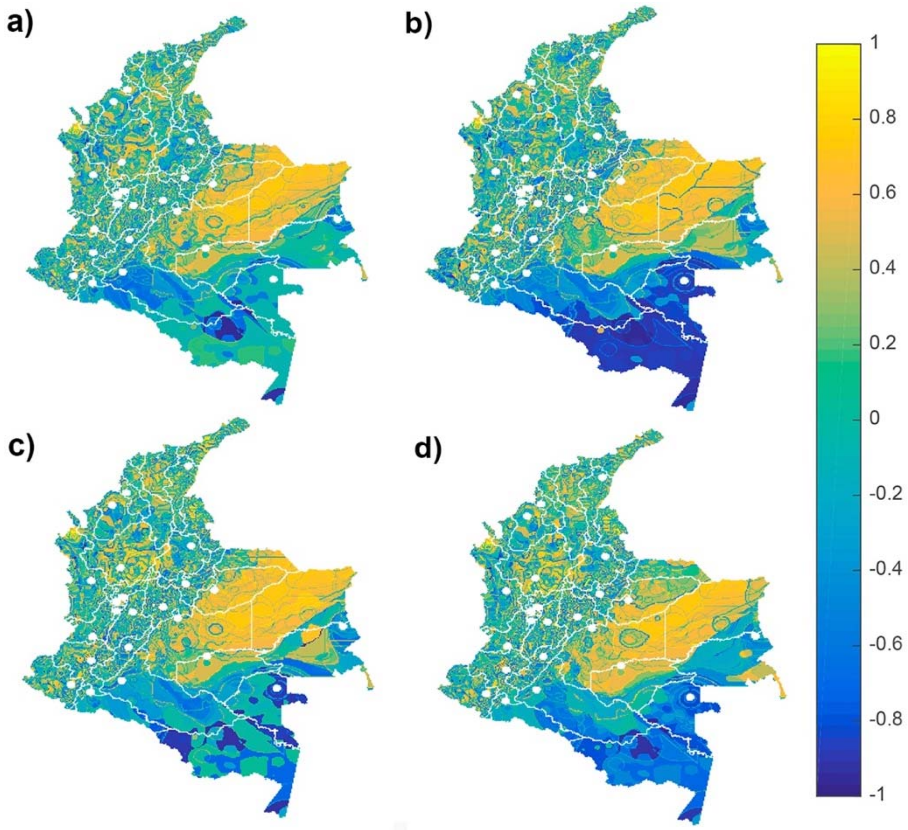

Fig. 9. Complementarity maps of Colombia: (a) May, (b) June, (c) July and (d) August.

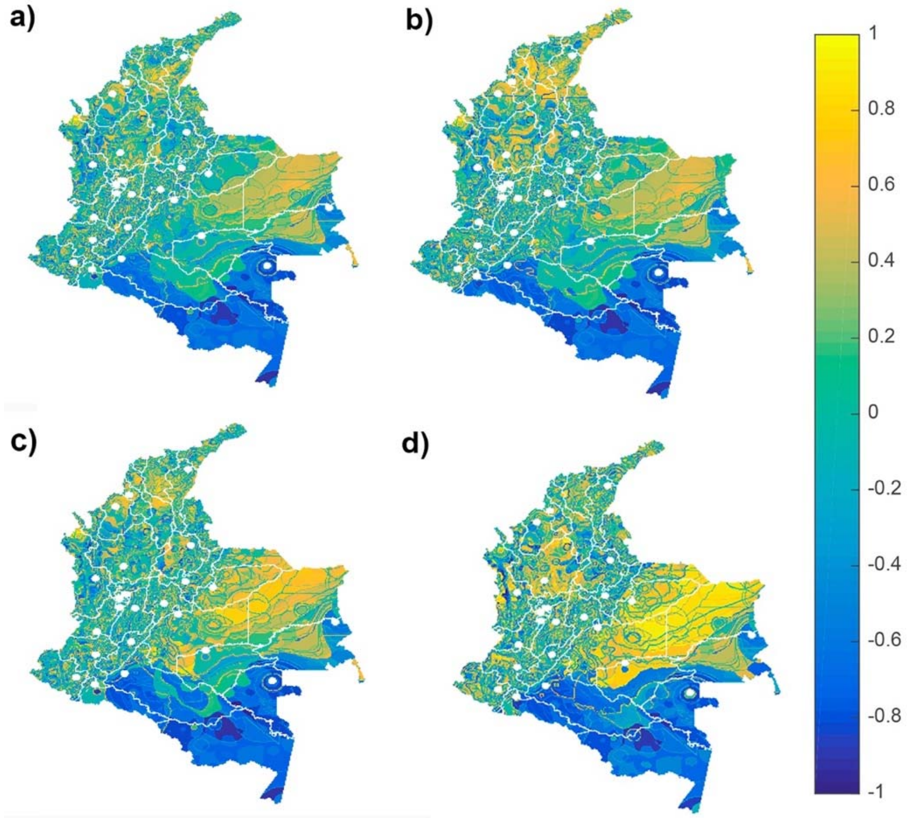

Fig. 10. Complementarity maps of Colombia: (a) September, (b) October, (c) November and (d) December.

5. Conclusions

A key part in the process of design and installation of power electric plants based on renewable energy sources is the assessment of the feasibility of installation, in terms of the availability of the resource. Also, it is important to note that the combined use of two or more renewable energy sources makes possible to do the best use of their operating characteristics, because, the combined use helps to cope the problem of the intermittence of the raw material.

Colombia is a country rich in biodiversity, natural resources and fertile land. Such is the case of wind and solar resources, and because of this, it has a great potential for the installation of photovoltaic panels and wind turbines.

In this paper the complementarity of solar and wind energy generation over Colombia was presented. The complementarity was calculated based on the Pearson correlation coefficient and the data extracted from the resources maps using image processing techniques. The results obtained show a good degree of complementarity between these renewable energy resources in specific places of the country. The degree of complementarity varies month to month and helps to identify sites of great potential of a combined used of solar and wind energy generation systems.

It is important to take into account that the results obtained are a good approximation of the reality, but some inaccuracies are introduced in the process of calculation, therefore it is necessary to carry out more careful assessment studies based on real measurements, in small regions identified with a good potential according with the obtained maps and considering other scales of time, for instance, days instead months.

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