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Assessing wind and solar resources. Case study: department of Norte de Santander, Colombia, stage 1

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Abstract. Renewable sources used to produce energy has gained momentum due to its environmental benefits and economic feasibility. Colombia has been part of the global tendency to develop non-conventional renewable technologies such as wind and solar and integrate those technologies into the energy matrix of the country. However, the lack of understanding of the wind and solar resources in some areas of the country including the department of Norte de Santander, Colombia, has limited the deployment of these technologies and the development of new projects. This research proposes an approach to assess wind and solar resources in the department of Norte de Santander, Colombia. Also, this paper discusses the physics behind the generation of energy from wind and solar sources and the contributions required from different backgrounds to help in the wide deployment of solar and wind energy. In this first stage, a rough technical concept is developed, and the proposed sites are selected based on publicly available maps of low resolution presenting average irradiance and wind speed, and proximity to electricity transmission infrastructure. The areas selected have a global horizontal irradiance ranging from 4.0 kWh/m² to 5.0 kWh/m² and wind speeds between 4.0 m/s and 6.0 m/s at 10.0 m height on average in a year.

1. Introduction

People consciousness and awareness about climate change have been growing and therefore initiatives to mitigate and avoid the catastrophic effects of climate change have seen an increased in support. Renewable energy technologies have been growing rapidly, especially in the last decade, in multiple application including utility-scale and distributed power generation. Renewable energy can be obtained using several different technologies. Colombia has been part of the global tendency to deploy renewable technologies and integration of those technologies into the energy matrix of the country. More recently the Colombian government has provided incentives to develop “non-conventional” renewable energy projects, being solar photovoltaic (PV) and wind energy the most popular technologies. Renewable technologies have been divided into conventional and non-conventional renewable technologies. The most popular, widely deployed and more economically viable “non-conventional” renewable (NCRE) technologies at the moment are solar PV and wind energy [1]. Despite these technologies have obtained an advanced degree of maturity are still considered NCRE due to the significant difference in matureness compared with hydro energy [2]. The NCRE projects are those which have minimal social and environmental impacts, besides of course of the positive impact of generating energy from renewable resources.

The use of solar PV in Colombia at both utility scale and distributed levels have increased in the last couple of years [3]. The unexploited potential of the solar resource in the country has been highlighted by financial institutions such as the World Bank Group [4]. Similarly, wind energy has obtained



attention from investors and local government given the particular good conditions in the northern area of the country to develop wind farms. However, the lack of understanding of the wind and solar resources in some areas of the country such as the department of Norte de Santander, Colombia, as well as the absence of historical data and reference projects in the area have limited the progress of these technologies in the department. Therefore, it is paramount to conduct a research that allows to thoroughly comprehend the potential of these resources (solar and wind) and to understand the basic physics behind it.

In addition, developers have experienced issues in finding local expertise with general technical skills within the renewable energy generation sector. Similar to what have happened in the past in developed countries around 15 years ago when a transition towards a cleaner energy supply encountered limitations in the availability of skilled workers, the local market is now constrained. In the case of the United Kingdom (UK) for example, it was widely discussed, and efforts were made to involve physicists and promote the contribution in research, development and demonstration (RDD) in the renewable energy sector [5]. The contribution of multidisciplinary backgrounds is required to help the sector evolve in Colombia and specially in the department of Norte de Santander, Colombia. This paper aims to promote the study and research of renewable technologies in the region by providing a high-level explanation of the physics behind the assessment of solar and wind resources.

Wind is considered by many as another form of solar energy, this is due to the variability of the wind given the atmospheric conditions (temperature and pressure) which are determined by the solar radiation. Solar radiation is absorbed by the earth surface, given the earth is made of different surface types (grass, sand, water, etc.) the heat distribution is uneven. The uneven distribution of heat creates a difference in temperature. This temperature difference creates convective forces that allows the air flowing. Warm air is lighter (weights less than cold air) therefore cool air moves replacing the rising warm air under standard conditions.

The earth moves around the sun while rotating around its own axis, therefore the irradiance of the sun to any point on earth varies along the day. It also varies along the year given the asymmetric shape of the earth and the orbital trajectory path followed around the sun. Thus, far from a constant value the irradiance of the sun on a particular point on earth is variable. In addition, the effect of clouds and others (such as contamination) also exacerbates the variability of the irradiance from the sun on a particular point on the earth's surface [6].

2. Solar photovoltaic

Solar PV power resource potential is directly linked to the global horizontal irradiance (GHI) reaching a certain point (usually defined as a square meter (m^2)). The GHI varies along the time according with the position of the sun with respect to the reference point. Therefore, different values of GHI are obtained along the day. Global horizontal irradiance (G_o) can be modelled for a horizontal plane parallel to the surface of the earth with a clear sky model, in which shading, cloud cover and air mass refractions of the sun light are neglected. A very simple sky model can be created using the solar constant (G_{SC}), which represents the radiation emitted from the sun, the day of the year (n) in which the estimation wants to be made, the declination angle (δ) representing the angular position of the sun at noon with respect to the plane of the equator, the hour angle (ω) defining the angular displacement of the sun east or west of the local meridian due to the rotation of the earth around its own axis at 15° per hour, and the latitude of the location assessed (ϕ) as expressed in Equation (1).

$$G_o = G_{SC} \left(1 + 0.033 \cos \frac{360n}{365} \right) * (\cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta). \quad (1)$$

However, the simple modeled described above as previously mentioned does not take into account cloud conditions over the defined area which may vary significantly along the year for a single place, thus significant changes on GHI are experienced across different months and seasons [7]. Colombia is located in the equatorial zone which provides a particular steady behavior of the solar characteristics

along any particular year, having negligible difference in the number of sun irradiance hours. However, the country is also located in complex climatic area where conditions may vary significantly [8].

The National mining and energy planning unit in Colombia “Unidad de Planeación Minero Energética (UPME)” has supported the development of a solar atlas for the country in an effort to characterize the solar potential and defined the most suitable areas to deploy solar PV technology [9]. Figure 1 shows the atlas developed by the UPME; it is noted that the department of Norte de Santander has a significant potential given the average GHI.

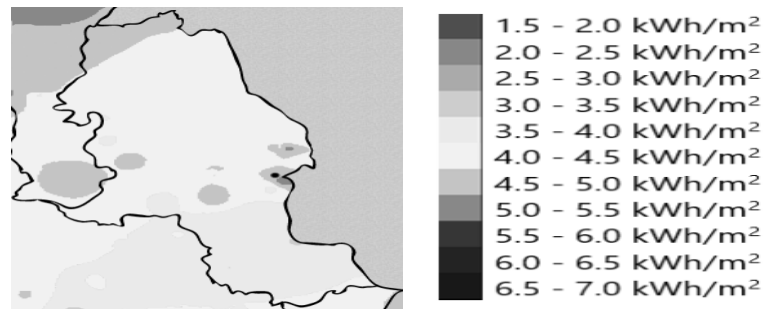


Figure 1. Long term daily average of global horizontal irradiance.

3. Wind energy

The energy from wind can be extracted by converting the kinetic energy associated with this into a force. Power (P) can be defined in terms of kinetic energy (E) and it is related the cross-sectional area air is flowing through (A), the density of air ρ_a and the velocity of the air (v) as shown in Equation (2).

$$P = E * t^{-1} = \frac{1}{2} * A * \rho_a * v^3. \quad (2)$$

Therefore, one can easily note that power is proportional to the cube of the wind speed. Although the maximum extractable power from the wind is defined by the denominated “Betz limit”, it is a fact that the most influential component is the speed of the wind. Thus, selecting a site with higher wind speeds will be far more beneficial (profitable) for the development of a wind energy project than a site with lower wind speeds. However, characterizing the wind behavior for any particular zone is a complex exercise given the multiple variables affecting its compartment [10].

The meteorologically complex conditions of the Andes area, by which most of Colombia is affected, combined with the lack of reliable historical data make it difficult to define the wind characteristics. Nevertheless, the UPME has combined efforts with the “Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)” to create a wind atlas for the country [11]. As shown in Figure 2 there is an area of slightly higher wind speeds in the western part of the department of Norte de Santander.

The reliability of the data used to produce the atlas cannot be confirmed, however, that is the best source of information to take an initial approach to define the area in which the scope of this assessment will be performed.

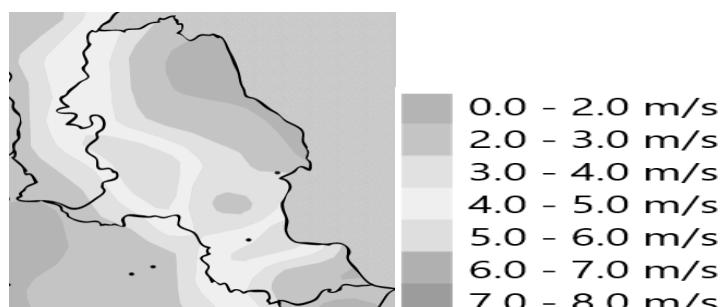


Figure 2. Long term average wind speed at 10.0 m height.

4. Concept development

The Colombian government plans to promote the development of non-conventional renewable energy projects in the country [12], for this, the UPME hold the first unconventional renewable energy auction and released the results of the winner bids on 24th October 2019 (after an initial failed attempt in February 2019 due to anti-trust concerns). In this auction, nearly 2.2 GW of combined solar PV and wind power coming from 8 new projects were allocated. The eight winning projects (3 solar farms and 5 wind farms) entered into 15-years power purchase agreements (PPA) with a condition to start generation not later than 1st January 2022.

Energy demand in Colombia is expected to growth around 2% per year for the next 30 years. Given the current conditions of the electricity market in Colombia there is still a need for developing of new renewable projects to reduce the dependency of hydro power plants which are greatly affected by meteorological adverse conditions produced by climate phenomena such as “El Nino” [13]. The department of Norte de Santander mainly consumes energy from coal fired power plants installed near the capital of the -and main load- and hydroelectric built in nearby departments. However, previously announced projects of new coal fired power plants have been cancelled as a result of the new policies implemented and the lack of interest in new investments on non-renewable technologies. Nevertheless, there is still a growing demand that needs to be cover thus a business opportunity for investors interested in developing renewable energy projects in the region.

A rough concept has been developed for the assessment of the solar resource, in this, the average irradiance values reported by the national mining and energy planning unit in Colombia [9] have been crosschecked against the results obtained from the clear sky model developed using Equation (1) for one year for the locations assessed. The clear sky model, as expected, overestimates the irradiance values when compared with the results presented in the solar irradiance atlas used. It was anticipated as the values presented are based on ground measured data by meteorological stations and are feed into robust climate models which better predict the irradiance for the areas assessed.

The assessment of the wind resource and validation of the wind data presented in the atlas used for the selection of the prospect areas is more difficult as it requires a wider understanding of the wind flow conditions across the department and will be part of the second stage of this research. However, it is known that the wind speed is affected by friction caused by the surface of the earth. Therefore, finding an area with orography that promotes an increase in wind speed under standard conditions is suggested. Also, an area with low roughness (low friction surface) and minor obstacles (topography or buildings that may restrict the wind flow) is desired. A simplistic approach to have an indication of the expected wind speeds may be followed using the wind shear theory if wind speeds at another height were available or if the roughness of the terrain is known. Thus, a wind speed (v) at a desired height (z) can be expressed in terms of a reference wind speed (v_{ref}) at a lower height (z_{ref}), and the roughness length (z_0) of the terrain in the direction that the wind is flowing using Equation (3).

$$v = v_{ref} \ln(z/z_0) / \ln(z_{ref}/z_0). \quad (3)$$

4.1. Transmission lines and substations

The Colombian electricity transmission system consist of substations, national transmission lines, regional transmission lines and international interconnections. A publicly available map including the national transmission lines routes was found, this line dataset represents electricity high voltage transmission lines under in Colombia for the year 2013 [14]. The keyhole markup zip (KMZ) file was uploaded to Google Earth to help in the identification of the potential site. The authors noted this map only includes the transmission lines from the national transmission system (STN by its abbreviation in Spanish) however, it is considered to be enough for an initial approach. Figure 3 shows the location of the substations and transmission lines paths in the department of Norte de Santander, Colombia.

Three additional substations, part of the regional transmission system (STR by its abbreviation in Spanish), were added for reference, Figure 4. Coordinates were obtained from publicly available

information. However, the actual path of the transmission lines connecting these substations is not publicly available.



Figure 3. Transmission lines, and substations of the department of Norte de Santander.



Figure 4. Regional transmission system substations.

4.2. Solar photovoltaic prospect areas

Two areas were selected for a further study of the solar resource in the next stage of this research. These areas were selected following the indicative map for solar resource shown in Figure 1, the proximity to the substations and loads (simplified points of energy consumption) and the topography of the area. The selected areas have low variations on elevation which is ideal for the development of a solar PV project. The prospect areas are shown in Figure 5.

4.3. Wind prospect areas

A single area was selected for a further study of the wind resource in the next stage of this research. This area was selected following the indicative map for wind resource shown in Figure 2, the proximity to the substation connected to the national transmission system and the topography of the area. The selected area includes multiples ridges with elevations circa 2900 m above sea level. The prospect area is shown in Figure 5.

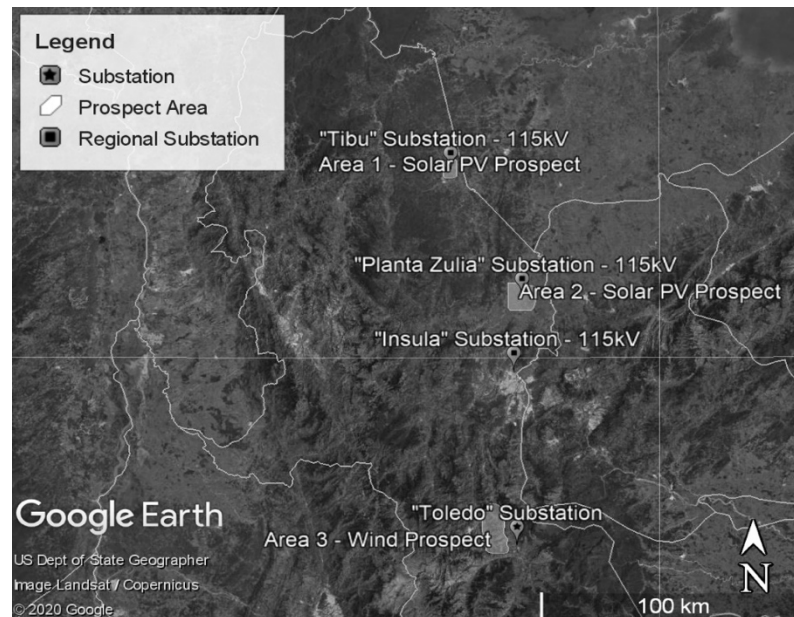


Figure 5. Prospect areas selected for wind and solar resource assessments.

5. Conclusions

This paper discussed the physics behind the generation of energy from wind and solar sources in an effort to provide a high-level review of the technical concepts and promote the study and research of renewable technologies in the region. The authors highlighted the need of intellectual contributions from different backgrounds to help in the deployment of solar and wind energy in Colombia. The case of UK, where physicians have involved in RDD within the renewable energy sector shows the importance of a multidisciplinary contributions. The areas selected have a global horizontal irradiance ranging from 4.0 kWh/m² to 5.0 kWh/m² and wind speeds between 4.0 m/s and 6.0 m/s at 10.0m height on average in a year. The clear sky model developed to assess the solar resource, as expected, overestimated the irradiance values reported in the solar irradiance atlas used for the selection of the prospect areas.

According to the wind shear theory, a suitable wind speed for development of a wind farm project may be experienced at the area selected if the topographic obstacles of the complex terrain surrounding this area do not have a great effect in reduction of the wind speed and the roughness of the terrain. The authors did not take into account rated capacity and current loads of the existing infrastructure when selecting the prospect areas. It is noted that upgrades on the capacity of the existing infrastructure are being planned as mentioned in the transmission expansion plan to 2025 released by UPME [15]. The next stage of the research will include a technical feasibility study in which the resource potential in the selected zones will be assessed. For this, measured data from publicly available resources will be used as well as data from climatological reanalysis methods such as ERA-5 and satellite derived datasets to assess the wind and solar resources. A third stage is also planned and will discuss the economic, financial and social aspects to developed projects in the zones selected the assessment of the solar resource over areas 1 and 2, as well as the assessment of the wind resource over the area 3.

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