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Potential Assessment of Renewable Energy Sources in Non-interconnected Zones of Colombia, using Geographic Information System - ArcGIS: Study of Cases

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The aim of this research is assessing energy potential of solar, wind, hydro, and agricultural residue biomass sources and choose the best option for the municipals of three departments with the highest energy demand in non-interconnected zones of Colombia. Energy potential assessment is carried out by using ArcGIS software, since it allows to represent geographic dispersion; climatic variables; terrain elevations; and territorial restrictions (social and environmental) such as the presence of indigenous reservations, armed groups, and natural parks. The results show that the water resource is the best choice in Chocó's towns; agricultural residue biomass has the greatest potential in Putumayo's towns, and the most viable option for Meta's towns is the solar resource.

1. Introduction

Nowadays, energy dependence on fossil fuels (in terms of primary energy consumption representing an average of 35 % oil, 27 % coal, 23 % natural gas, and the rest from alternative energies) triggers significant concerns, as they are not RES (Renewable Energy Sources) (Mark and Delucchi, 2011). Furthermore, fossil fuels cause serious environmental impacts such as climate change (particularly loss of the Arctic sea ice cap), air pollution, and acid rain. All of the above problems have produced several political and economic conflicts that have increased the world investment in research, development and application of alternative technologies for energy generation. In addition, energy production is necessary for a country development since it is essential for everyday activities such as lighting, using electrical devices, transport, livelihoods, and education by increasing employment opportunities that lead to economic and social benefits. Though, nearly 1.4 billion people still lack access to electricity (87 % of whom live in rural areas), and one billion has access only to untrusted networks of electricity. It is estimated that the capital investment needed to provide modern energy services to this population is about $ 40 billion per year, until 2030. This value represents about 3 % of the total investment in energy worldwide that is expected for this period (Grynspan, 2011).
In the case of Colombia, approximately 421,000 households do not have electricity service, which 57 % in not connect to the NIS (National Interconnection System) due to most of these households are located in NIZ (non-interconnected zones) that are characterized by low population density (4 %), public services limited and undeveloped, people's basic needs unsatisfied, covering almost 66 % of the national territory including nearby 1,200 settlements, 16 departments, 91 tows and 2 million people (Castro and Hernández, 2010). These zones do not have appropriate access routes (isolated), lack industrial and commercial development, public services are limited and undeveloped, and people's basic needs are unsatisfied (Rosso-Cerón et. al, 2015). Paradoxically, NIS have great environmental importance with a wide variety of natural resources (water, solar, wind, and biomass) that can be exploited for the production of clean energy, as long as sustainability issues like population growth, industry, environmental disturbance, financial resources, social welfare, and cultural development are took into account.
Therefore, endogenous RES became an option for assisting such isolated consumers if compared to difficulties and cost of imported resource. Moreover, they have inherent advantages such as CO_2 reduction

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due to the reduction of diesel oil consumption (the most used option) and the possibility of developing local productive activities in the communities.

In this sense, Colombia has an average wind energy potential of about 6 m/s, except in the Caribbean Coast (IDEAM-UPME, 2006), where it is higher; a daily average solar potential close to 4.5 kWh /m^2 year (Marín, 2003), being prominent areas of the North and the East; water supply in terms of performance of 58 l/s per km² (TWENERGY); and the biomass source has a potential of 16 GWh/y (CORPOEMA, 2012) since the country has a variety of crops throughout the national territory which residues can be used to produce fuel, electricity, and heat. On the other hand, geothermal and ocean resources have only been preliminarily studied (UPME, 2013). These studies have shown that the country is placed in an area of high geological activity, highlighting the Ring of Fire which is part of the national territory, this implies a possible use of this energy, for example in the del Ruiz volcano it is possible to find fields that operate at temperatures between 200 °C and 250 °C (UPME, 2013). However, the high costs associated with the geothermal installation affect the plant performance due to in these areas the energy demand is not very high (UPME, 2013).

Although previous studies have estimated the RES potential at national level (Quijano et al., 2012 and UPME, 2006), they have not considerate the lack of updated and complete databases of RES at local level, then particular studies for each area of interest should be implemented to obtain more accurate resource values. On the other hand, the use of developed countries' software such as METEONORM is not suitable to determine energy potential in Latin America, since its database has no accurate information on weather stations, and data interpolation techniques involve wrong information.

Therefore, the aim of this study is to assess RES potential at local level and choose the best option for the municipals of three departments with the highest energy demand from NIZ: Meta, Chocó, and Putumayo. Potentials are estimated using the software of ArcGIS and considered social and environmental restrictions like the presence of indigenous reservations, armed groups, road access, natural parks, etc.

2. Selection of study of cases

In this stage were selected three non-interconnected departments: Meta, Chocó and Putumayo, which satisfying the following conditions:

•That does not have plans connection to the national grid.
•Large population benefited and high residential energy demand.
•That is not part of an indigenous reservation or forest reserve.
•That there are no problems of armed conflict.

3. Assessment Renewable Energy Resources

RES potentials were determined using the ArcGIS 10.1 software. This software is able to process information of maps in shape file format, sort areas with particular conditions, and constrain the slope, the water reservoirs, and the protected areas (national parks and indigenous reserves, national roads, and cultivation areas) (IGAC, 2013). It has been used the MAGNA-SIRGA (National Geocentric Framework) as georeferencing system, which guarantees the compatibility of Colombian coordinates with spatial positioning techniques, such as GNSS (Global Navigation Satellite Systems), and international sets of georeferenced data.

3.1 Solar Potential

In order to estimate the solar potential theoretical data of daily solar radiation (from 2005 to 2014) were used the database of weather stations NASA, through the RET Screen software. As Colombia is located in the equatorial line, the tilt angle for the photovoltaic panels is considered zero (Esteve, 2011) and only the data of radiation on horizontal surface were used. Hence, for estimating the multiyear average daily radiation (solar potential), data from all stations in each study area were averaged by using the spatial estimation technique stochastic ordinary Kriging, available in ArcGIS, Eq. (1).

$$Z(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \qquad (1)$$

Z (S_i): measured value at the location i (in this case de solar potential), λ_i: weight for the measured value to the location I, S_0: Location prediction, and N: number of measured values.

3.2 Biomass Potential

The potential of biomass of agricultural residues each study area was estimated from permanent crops with the largest production between 2009 and 2014 (plantain: spine, the rod and plantain discard; yucca: husk, leaves, stems and discard yucca; pineapple: peel, heart, pruning and pineapple discard; oil palm: husk, fiber and rachis; and sugarcane: bagasse and leaves) (Agronet, 2007-2014). Moreover, according to Dong et al. (2012) collect between 30 % and 70 % biomass residues do not significantly affect the stability of the soil. This percentage varies depending on weather, demand for nutrients and type of residue. In order to take into account the variation of the parameters listed above, the most realistic scenario is to use 30 % of the residues (Baruah, et al., 2014). Furthermore, the energy potential of a crop directly relates the amount of energy (lower heating value) and the amount of mass of residue generated. The mathematical model is based on Bilsborrow and Lye, (2013):

$$EP = \sum_{j=1}^{k}\sum_{i=1}^{n} WM(i,j)\cdot LPV(i,j) \quad (2)$$

EP: energy potential, k: number of crops, n: types certain crop residues, WM: mass of residue generated.
Three parameters in the models are required to determine the amount of residue: the planted area, crop yield (Baruah et al., 2014) and the ratio of residue mass produced by major product obtained (Cardona et al., 2010). The mass of residue generated can be expressed as follow:

$$RM = \sum_{i=1}^{n} CA(j)\cdot YC(j)\cdot RWM(i) \quad (3)$$

CA: cultivated area, YC: crop yield, and RWM: ratio of residue mass.

3.3 Wind Potential

In order to estimate the wind potential data speed and air density are needed. They were used wind speeds obtained from the database of NASA through the RETScreen software, which were measured between 2005 and 2014 at 10 m height. The speed at 10 m height is scaled to 50 m using the Lysen model profile (Narvaez, 2010) Eq. (4). The Kriging interpolation method was used to estimate the values of wind speed and wind power density in the case studies.

$$V(Z) = V(Z_r)\left(\frac{Z}{Z_r}\right)^{\left[\ln(Z/Z_r)/\ln(Z_0/Z_r)\right]} \quad (4)$$

V(Z): wind speed at Z , $V(Z_r)$: wind speed at 10m height, Z_0: surface roughness and Z: new height
To calculate the air density, the equation of state of ideal gas was used:

$$\rho = \frac{P}{RT} \quad (5)$$

P: pressure [Pa], R: universal gas constant [J/ (Kg K)], and T: temperature [K].
To assess the real air density, constant R must depend on the vapour pressure of air:

$$R^* = R\left(1+\frac{3e}{8P}\right) \quad (6)$$

$$e = \exp(-67637/T) - 4.9283\ln(T) + 54.23 \quad (7)$$

The atmospheric pressure and air temperature were evaluated by the mesoscale meteorological model MM5:

$$P_{SO} = P_{00}(P_{00}/850)^{-\frac{Z}{H_{850}}} \quad (8)$$

$$T_0 = T_{S0} + A\ln(P_{S0}/P_{00}) \quad (9)$$

P_{00}: sea level pressure, T_{S0}: reference temperature at P_{00}, A: change rate at 50 K, P_{00} = 1008 hPa, T_{S0} =300 K.
After the speed and density of the air were obtained, the wind potential was calculated as follows:

$$\frac{P}{A} = \frac{1}{2}\rho\frac{1}{N}\sum_{n=1}^{N} V_n^3 \quad (10)$$

P/A: power density [W/m²], ρ: air density [kg/m³], V: air speed [m/s], and N: number of data.

3.4 Water Potential

The water potential depends on the rivers flow and the terrain height, these variables were determined through the ASTER DEM (Digital Elevation Model) digital elevation mode from NASA and hydrology tools available on the ArcGIS software. The rivers were selected from hydrology tools of digital elevation model as shown below:
The mass conservation equation of the control system is used for a period of a year. According to Beleño, (2014), the water balance is:

$$\overline{Q} = \int [RF - E]dA \quad (11)$$

RF: average rainfall (mm/y), E: blade of water lost by evapotranspiration, and dA: differential area.

The technique of stochastic space estimation (Ordinary Kriging) of ArcGIS software was employed to calculate the fields of rainfall and evapotranspiration in the study area.

Rainfall data from case studies and its surroundings were supplied by IDEAM. In the case of the evapotranspiration, the data were determined with the Turc method due to it was validated with the case of Beleño (2014).

$$RET = \frac{RF}{\sqrt{0.9 + \frac{RF^2}{L^2}}} \tag{12}$$

L = 300 + 0.05 25 T + T^2, RET: evapotranspiration (mm/y), RF: rainfall (mm/y), Lc: line length, and T: average temperature (°C).

Due to the lack of data in the national meteorological stations, the temperature data were estimated by the regionalization method proposed by Chavez and Jaramillo, (1998).

For assessing the water potential was necessary to locate two points on the rivers and to meet the following relation:

$$\frac{Lc}{Hn} \leq 25 \tag{13}$$

Finally, the hydro potential was calculated as follows:

$$WP = 9.81 \cdot Q \cdot H_n \cdot e \tag{14}$$

WP: potential (kW), Q: design flow, H_n: net fall, and e: plant efficiency (0.85).

4. Result and discussion

According to the results obtained with Eq. (1), the average values of solar potential are between 4.0 and 4.2 kWh/m² in most of the municipalities. The department of Meta has the greatest solar potential with values between 4.2 and 4.8 kWh/m² (Figure 1); in the second place is the case of Chocó with potential level between 4.0 and 5.0 kWh/m²; and finally, the department of Putumayo, where the radiation is around 4.0 and 4.6 kWh/m². These values indicate that the solar resource is suitable for energy generation in the 3 cases of study, because the range goes from 4.0 to 4.5 kWh/m² (UPME and IDEAM, 2006).

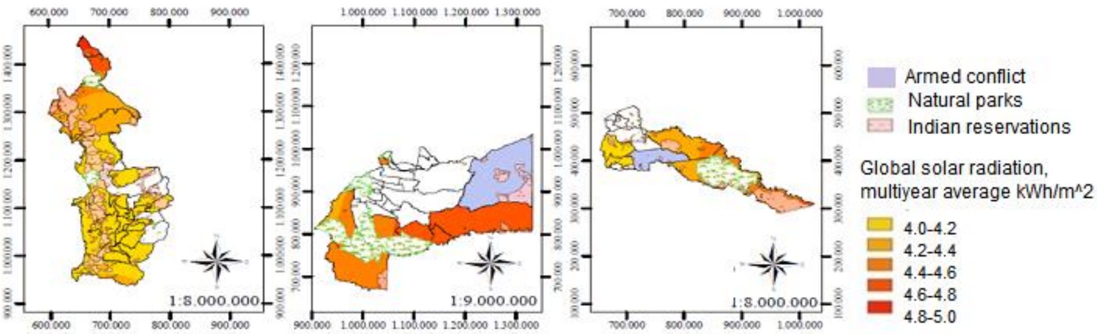

Figure 1: Solar potential level of Chocó, Meta and Putumayo, respectively

The biomass potential results obtained from Eq. (2) are shown in the Figure 2. The plantain residues have the greatest potential with a total of 492.3 GWh/y and it is distributed in 59 % from the department of Choco, 15 % from Meta and the remaining 26 % from Putumayo. On the other hand, the lowest potential comes from pineapple residues, with 11 GWh/y and which is only representative in the department of Chocó.

It is pointing out that the department of Chocó has the greatest potential with 733 GWh/y, followed by Meta and Putumayo, respectively. According to Cardona et al. (2010), these values of residual biomass are feasible for the production of energy in all cases, however, the selection of the conversion technology to be used depends on other parameters such as humidity, ash content, among others.

In the case of wind resource, Meta and Putumayo departments have wind speeds ranges between 1.0 and 3.0 m/s (3-12 W/ m^2), Figure 3. Nevertheless, according to the Beaufort scale, wind speeds between 1.6 and 5.3 m/s correspond to a very weak or faint breeze, this means that speed ranges are not enough for a wind turbine work because they begin to rotate from 3 m/s.

In the case of Choco the wind potential goes from 3 to 60 W/m², which represent wind speeds between 2.0 and 4.0 m/s. These values allow the production of work in the wind turbines, but they are not enough for operating at their nominal power and it results in low power and high costs, then wind potential is not viable in any of the cases of study. From the database of UPME and IDEAM (from 1981 to 2010), multiyear precipitation maps were generated. Hence from Eq. (12), the evapotranspiration maps were obtained. The results of the Eq. (11) indicate that in the department of Chocó the level of rainfall and evapotranspiration have the greatest values among all the cases. In order to give validity to the rainfall and evapotranspiration values, the results obtained for the case of Chocó were compared with data reported by the IIAP (2013), whose averages represent an error less than 8.40%. The Figure 4 shows the results obtained from Eq. (14). Due to the hydro potential levels are above 20 MW/y it is possible to use the water resources in all departments. It is important to point out that like it was expected the greatest hydro potential values are in Chocó, followed by Putumayo, and Meta, respectively.

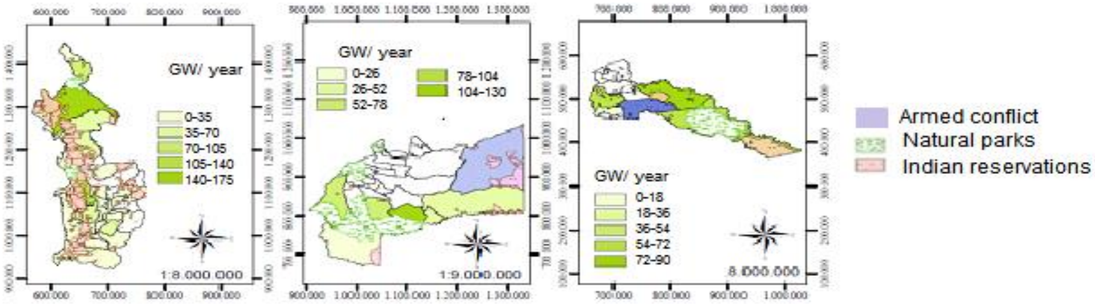

Figure 2: Biomass potential level in Chocó, Meta, and Putumayo, respectively

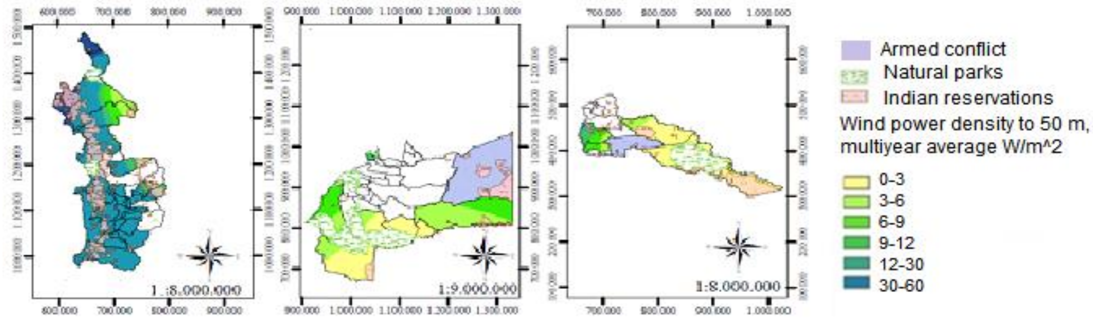

Figure 3: Wind potential level in Chocó, Meta and Putumayo, respectively

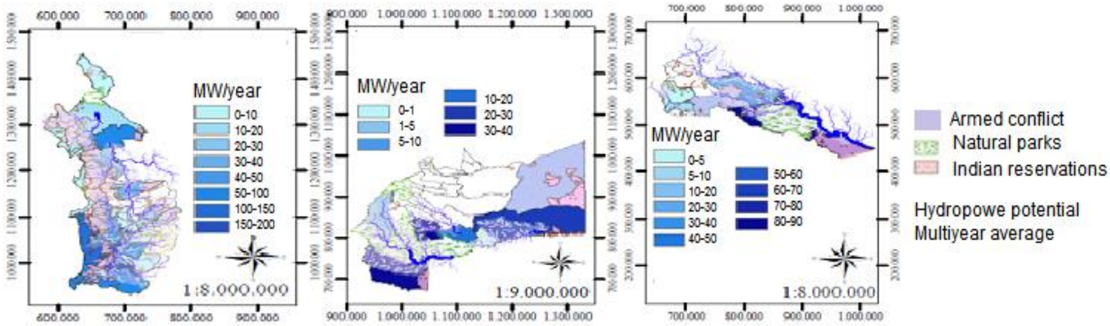

Figure 4. Hydro potential level in Chocó, Meta, and Putumayo

5. Conclusions

This study assessing the energy potential of residual biomass, solar, water and wind resources by using a methodology, which includes the use of ArGIS in combination with the information available on national and international data bases. High values of solar, water and residue biomass potentials are usable in 3 of the cases of study. The water resource is the best choice in Chocó's towns; while the residual biomass has the greatest potential in Putumayo's towns, and solar resource is the most viable option for Meta's towns. The wind resource is not a viable option for the energization of the study areas due to wind speeds are not suitable for running wind turbines and the potential is not enough to operate these systems efficiently. Finally, this work improves the almost non-existent database on RES potential at local level in Colombia and though the application is illustrated on cases of NIZ, the framework is applicable to other regions.

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