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ASSESSMENT OF WIND POTENTIAL ENERGY OF FOUR MAJOR CITIES IN CÔTE D'IVOIRE USING SATELLITE DATA FROM 2015 TO 2022 Daouda KONE 1,6, Souleymane TUO 2*, Kolotioloma Alama COULIBALY 3, Bi Tra Olivier GORE4 , Kouakou Bernard DJE 5, Mariam TRAORE2, Boko AKA6 * Corresponding Author : souleymane.tuo@univ-man.edu.ci Abstract In Côte d'Ivoire,
the use of renewable energy is becoming a
major challenge
in the context of climate change and
global warming. Therefore,
the aim of this study is to characterize the wind profile for potential energy in Abidjan, Man, Bouaké and Korhogo of Côte d'Ivoire using satellite data. Wind speed and direction data from Copernicus Centre from 2015 to 2022 are used for these major cities. The frequency method is used to build wind rose and power density formula to estimate the potential energy for each city, at ground level (10 meters) and in particular level at 100 meters and 500 meters. The results showed a slightly wind speed and direction variation from 2015 to 2022. This suggests that wind has a seasonal (wet and dry) evolution over the year. However, wind speeds increase for each city with the altitude. The higher average wind speed is observed in Abidjan
with a power density of 58 W/m2. The
lower wind speed and power density are observed in Man, Bouaké and Korhogo. So, the coastline of Côte d'Ivoire has the higher wind energy resource than the inland regions of the country. Keywords: Wind, speed, direction, energy, Côte d'Ivoire. 1. Introduction Electrical energy is indispensable for all socio-economic activities. This socio-economic development is often followed by atmospheric pollution due to the greenhouse gases emitted by the various types of energy used (XUANXUAN, et al., 2024). Climate change is becoming an increasingly pressing issue. As a result, one COP after another reminds us of the need to preserve the environment and the climate (GUGLIELMO, et al., 2023). In addition to preserving climate,
it is also necessary to diversify energy sources to ensure our energy
sovereignty (PRAENE, et al., 2021). Côte d'Ivoire is not on the sidelines of sustainable development objectives. Côte d'Ivoire's currently produces 70% of its energy for domestic use and plans to increase this to 99% up to 2030, including 42% from renewable energy. ((MPE), 2016). With the quick increase in population, major cities of Cote d'Ivoire, such as Abidjan, Bouaké, Man and Korhogo request huge amounts of energy to maintain and improve the level of their economic activities. Numerous studies are conducted in Africa in generally and west Africa in particularly (Awanou et al 1991, Bilal B et al 2008, Bekele G
et al 2009, Oyedepo et al 2012 , Ben U. C. et al
2021, Asamoah
et al 2023) in order to evaluate the potential of wind power in this area of the
world. Evaluation of wind speed was conducted in the coastal regions of Ghana. The results show a
wind speed varying between 3 m/s and 9 m/s
(Muyiwa S. Adaramola, 2014). It has been suggested that with suitable selection of wind power generators such as
wind turbine model CF-100 (with cut-in wind of 2.2 m/s and rated wind speed of 9.5 m/s
), wind energy could be also used to improve the mix of energy in the electrical production of the country (Muyiwa S. Adaramola, 2014) (Sarpong, 2015). In another study conducted in non-coastal areas, notably different cities of Mali, lower
wind speed between 3 .1 m/s and 5 .5 m/s
was obtained at various heights from 20 m to 50 m (Ivan Nygaard, et al., 2017) According to Côte d'Ivoire's state-owned energy management company, in order to meet its energy needs while protecting the environment in line with its international climate change commitments, Côte d'Ivoire is focusing on diversifying its energy sources by promoting green energy, in particular hydropower, biomass and solar energy (CI-ENERGIE, 2019). Côte d'Ivoire has wind every year, but wind energy is not developed and not used by the population. During the year, Côte d'Ivoire is blown by two major air masses, the monsoon and the harmattan (TAUPIN, et al., 2002) since this country is a part of the Gulf of Guinea. The monsoon is an oceanic wind that blows from South, while the harmattan blows from Northeast from Sahelian regions. Assessing the energy available from these winds

is an essential step not only in estimating the size of the wind
resource, but also in identifying
suitable sites for wind turbine installation in the
country. Recent study showed that maximum wind speed in Yamoussoukro, central part of Côte d'Ivoire varies between 3 .02 and 4 .96 m/s depending on the month of
year (Jean-Michel Soumien Kouadio, 2024). In this study, a measuring station was used to collect wind data in an urban area. Then, Souleymane TUO et al.(2023) showed that the wind in the region of Man is relatively weak with wind speed lower than 2
m/s at 10 m from the ground. The city of
Man is one of Côte d'Ivoire's mountainous regions (Souleymane TUO, 2023). However, these studies remain localised. In addition, they were carried out at an altitude of 10 meters. Wind resource prospecting at many altitudes higher than 10 meters is essential. Recently, Mariam et al. showed by comparing in situ data recorded at 10 meters from ground level in Man synoptic station that COPERNICUS satellite data are reliable and can therefore be used to assess wind energy potential
in Côte d'Ivoire (Mariam, et al ., 2023). In addition , they proposed the
use of satellite data to assess wind energy at different levels, thus compensating the lack of large-scale measurement stations in the country. This study uses satellite data to assess wind energy resources at different levels in Abidjan, Bouaké, Man and Korhogo, located in the South, Center, West and North of Côte d'Ivoire respectively.
Figure 1 shows the location of the selected
cities for this study in Côte d'Ivoire. Source:
Bureau National d'Etudes Techniques et de Développement (BNETD) Figure 1: Location of
the four main cities of the study
in Côte d'Ivoire Abidjan, Bouaké , Man and Korhogo belong to the
main homogenous rainfall pattern zones
of Côte d'Ivoire according to the
study of (COULIBALY, et al., 2019). The lack of observed wind data in these cities (synoptic stations) due to breakdown of the wind materials, led to exploring satellite data of Copernicus Center in this study. In addition, these cities are urbanized and densely populated. Industrialization, trade, services and transport dominate the economic activities in these cities. The topographic pattern of Côte d'Ivoire is generally dominated by plains and plateaus, except the Western part of the country where there are high mountains reaching more than 1,000 meters, such as Mount Nimba (1,752 meters). 2. Data and methods 2.1. Data Hourly wind data at different levels for 10 meters ; 100 meters and 500 meters from 2015 to 2022 are used in this work. This parameter has two components: speed and direction. These data were extracted for Abidjan, Bouaké, Man and Korhogo in the Copernicus climate database (HERSBACH, et al., 2023). The coordinates of the cities are given in table 1. Table 1. Coordinates of the study cities Stations Longitudes (°) Latitudes (°) Altitude (meters) Korhogo -5.62 9.42 381 Bouaké -5.07 7.73 375 Man -7.52 7.40 339 Abidjan -3.93 5.25 7 Source: Société d'exploitation et de développement aéroportuaire aéronautique et météorologique (SODEXAM
) 2.2. Methods 2.2.1. Frequency analysis for wind roses Frequency analysis for wind roses is used to obtain annual wind roses for each station. For this, wind roses are run with hourly data from 2015 to 2022. Wind roses show the dominant wind directions and speeds at a given time and location. 2.2.3. Power density method Power density
is a key parameter for assessing the wind potential of
an area. Considering
the air density ρ=1.225 kg /m3 and the average wind speed
V, the available power density is estimated by equation (TIESSE, 2020) (Adaramola et al 2014 and TIESSE 2020) $Préc = \times \rho \times V3$ 1 2 The power density of wind is be calculated for three levels (10; 100 and 500 meters). This density is also determined for each station.
3. Results and discussion 3.1 . Hourly wind speed Hourly wind speeds
over one year at 10 meters are analysed for Abidjan, Bouaké, Korhogo and Man. This analysis aims to show the period of maximum and minimum wind speeds for these locations. Source: Our treatments, 2024 Figure 2: Evolution of hourly wind speed in Abidjan, Bouaké, Korhogo and Man Figure 2 shows the evolution of hourly wind speed in Abidjan, Bouaké, Korhogo and Man. In Abidjan, hourly
wind speeds vary from 2 .5 to 3.3 m/s. The
minimum speed is reached in the morning at 6H and the maximum in the afternoon at 16H. In Bouaké, hourly wind speeds vary from 1.6 to 3.
2 m/s. The minimum speed is obtained at 18H in the afternoon and

the maximum at 8H in the morning. In the locality of Korhogo, hourly wind speeds vary from 1.8 to 3.2 m/s. The minimum speed is reached at night at 19H and the maximum in the morning at 10H. For Man, hourly wind speeds vary from 0 .8 to 1.4 m/s
. The minimum speed is reached at 17H in the afternoon and the maximum in the afternoon at 13H. 3.1. Interannual variability of wind speed at 10 ; 100 and 500 meters levels Figure 3 shows interannual variability of wind speed from 2015 to 2022 for Abidjan, Man, Bouaké and Korhogo in Cote d'Ivoire at the surface (level 10 meters). Source: Our treatments, 2024 Figure 3: Interannual evolution of wind speed at the surface (level 10 m) in Abidjan, Bouaké, Man and Korhogo This figure 3 shows
that the surface wind speed in Abidjan is higher than
Bouaké, Korhogo and Man over the period from 2015 to 2022. In Abidjan, the lowest
wind speed is 2 .4 m/s in 2020, while the highest is 4 .3 m/s in
2022. These results are in line with those published by the ECOWAS Renewable Energy Policy Baseline Report (CEDEAO, 2012). This high wind speed in Abidjan is due to its proximity to the Gulf of Guinea. Sea winds are stronger. The monsoon is a wet, strong wind that can provide considerable mechanical energy, making it ideal for wind farms. In Bouaké, Man and Korhogo, the lowest velocity value is 1.3 m/s and the highest is 2.7 m/s. Man has the lowest wind speed from 2015 to 2022. These ranges of wind speed
in Abidjan, Bouaké, Man and Korhogo show that the velocity of wind is
lower
in Côte d'Ivoire . So, in the Center, West and
North of Cote d'Ivoire, wind speed decreases with the presence of numerous obstacles at the surface (Ólafsson, 2000). This could explain why the wind is so weak in Man, a mountainous and forested area. Although there are similarities in the interannual variation of wind speeds in different locations, it is important to note that a particular type of wind dominates each location. Wind in Côte d'Ivoire is made up of two major air masses: the monsoon and the harmattan. The monsoon is a humid oceanic wind. It is more intense in the south, while the harmattan, dry, hot Sahelian wind dominates the North of the country (TAUPIN, et al., 2002). The predominance of each wind during the year is determined
by the position of the intertropical front (ITF). Thus, the
total wind speed at a given time of year in a given locality is dependent on the intensity of each of these two types of wind. After this analysis,
it is necessary to explore the profile of wind speed for different
levels in Abidjan, Bouaké, Man and Korhogo.
Figure 4 shows only the variation of wind speed
in Abidjan at 10 metres, 100 meters and 500 meters from 2015 to 2022. Abidjan Bouaké Man Korhogo Source: Our treatments, 2023 Figure 4: Evolution of wind speed profile for Abidjan, Bouaké, Man and Korhogo at 10 meters, 100 meters and 500 meters level from 2015 to 2022. Figure 4 shows that wind speed increases with the level (altitude) in Abidjan, Bouaké, Man and Korhogo. Determining the altitude from which wind speed is strong is an important parameter for wind turbine size. It also determines both the choice of the mast's height and the length of blades. To reach high altitudes, it's therefore essential to study vertical wind turbines. Wind speed is much higher for Abidjan than Bouaké, Man and Korhogo. So, Abidjan seems to be the best zone to implement Enercon wind turbines models (Soulouknga, 2022) or other model (Muyiwa S. Adaramola, 2014). Some wind turbines generally start to run at least with 2 m/s, and masts of varying heights (Mohamadi et al 2021, Ugur et 2013, Casini M. 2015 and Pallabazzer 1995). In fact, average wind speed at the surface (10 m) in Abidjan is more than 2 m/s. In Bouaké, Korhogo and especially Man, it is essential to explore high altitudes to get the minimum speed of 2 m/s for starting up industrial turbines. This result suits with the conclusion of (Mariam, et al., 2023) where they suggest exploring mountain peaks to increase wind turbine production for wind power
in Côte d'Ivoire and particularly in the
Tonpki region (Western part
of Côte d'Ivoire). The knowledge of wind direction is very important for the implementation of
turbines for wind power. Also, in Cote d'Ivoire there are two types of wind depending on seasons. So, the next section will explore wind dominant direction through wind roses at different levels. 3.2. Wind roses at 10 meters; 100 meters and 500 meters levels Figures 5 and 6 show wind roses at 10 meters, 100 meters and 500 meters for Abidjan, Bouaké, Man and Korhogo. They show the wind direction at different altitudes in each of the cities considered. Ayua et al (2023) presented a similar study on certain regions of Gambia. Wind roses of Abidjan, Bouaké, Man and Korhogo indicate the frequency of wind direction according to the speed distribution for levels 10; 100 and 500 m. In Abidjan, winds of 3.
5 m/s to 4 m/s

blow from the Southwest. These are monsoon winds. This type of wind also blows in Man, but at relatively low speeds of between 1.5 and 2 m/s. Winds in Bouaké are generally south-westerly. This suggests that the monsoon also governs Bouaké. The monsoon is the south-westerly wind that blows
in the north -east of Côte d'Ivoire. This type of wind is therefore dominant in the
southern (Abidjan), central (Bouaké) and western (Man) regions. However, in Korhogo, in the north of the country, two dominant wind directions are detected: north-easterly and south-westerly. These correspond to harmattan and monsoon winds respectively. In fact, the wind roses for Korhogo show that the intensity of the monsoon is reduced compared with the wind roses for Abidjan. In addition, a north-easterly wind appears, indicating the presence of the harmattan. As one moves away from the coastal regions, the monsoon becomes less intense and the harmattan increases. For Abidjan, Bouaké and Man, the dominante wind direction is Southwest for all levels. This confirms that the dominant wind in these regions is monsoonal. In Korhogo, two dominant wind directions are visible: South-westerly and North-easterly. The North-easterly direction indicates the dominance of harmattan. This confirms that Korhogo is generally blown by both monsoon and harmattan winds. Generally, whatever the level and the stations, the dominant direction of wind is Southwest and Northeast. The wind roses also show that wind speeds increase with altitude. It is therefore advisable to favour the high hills to capture high wind speeds for wind farm siting. WIND ROSE –ABIDJAN (10 m) WIND ROSE – BOUAKE (10 m) WIND ROSE –ABIDJAN (100 m) WIND ROSE – BOUAKE (100 m) WIND ROSE –ABIDJAN (500 m) WIND ROSE – BOUAKE (500 m) Source: Our treatments, 2023 Figure 5: Wind roses at 10 meters, 100 meters and 500 meters levels in Abidjan and Bouaké WIND ROSE – KORHOGO (10 m) WIND ROSE – MAN (10 m) WIND ROSE – KORHOGO (100 m) WIND ROSE – MAN (100 m) WIND ROSE – KORHOGO (500 m WIND ROSE – MAN (500 m) Source: Our treatments, 2023 Figure 6: Wind roses at 10 meters; 100 meters and 500 meters in Korhogo and Man After characterizing wind speed and direction for different levels
in Abidjan, Bouaké, Man and Korhogo , it is important to
analyse
the potential of wind to contribute to the production of wind power
. This is important because wind power is considered as a renewable energy which can be implemented in Cote d'Ivoire. 3.3. Wind power at different altitudes Figure 6 shows wind power densities at different altitudes 10 meters; 100 meters and 500 meters for Abidjan, Bouaké, Man and Korhogo. Source: Our treatments, 2024 Figure 6: Wind power density as a function of height
in Abidjan, Bouaké , Man and Korhogo For Abidjan, Bouaké , Man and Korhogo
, power density is low at 10 meters near the surface. However, it increases significantly with height. In Abidjan, power density varies from 19
W/m2 at 10 m to 58 W/m2 at
500 meters. In Abidjan, Bouaké and Korhogo, power density is almost tripled between 10 meters and 500 meters altitude. In Man, power density remains low even at 500 meters. The wind is globally considered as calm in this city (Souleymane TUO, 2023). This may be due to the topographical characteristics of the
typically mountainous
in this Western part of Cote d'Ivoire . Indeed, the
Man region is surrounded by mountain ranges. These mountains seem to create an obstacle to the circular movement of the wind, thus reducing its power. For this reason, it would be wise for this area to make use of the mountain peaks. These mountains can reach heights of over 1000 meters (Naon, 2019). 4. Conclusion This work is carried out to assess wind energy potential for
Abidjan, Bouaké, Man and Korhogo in Côte d'Ivoire
, using satellite data. The availability of satellite data at different altitudes made it possible to overcome the limitations of ground observations. The study showed that wind speed in Abidjan is higher than the wind in Bouaké and Korhogo. Abidjan has a density of 58 W/m2 at an altitude of 500 meters, compared to 38 W/m2 and 27 W/m2 for Bouaké and Korhogo respectively
. Man has the lowest wind potential, with only 3 W/m2 at 500 meters. Furthermore, wind speed and power density increase with the altitude Abidjan, Bouaké, Man and Korhogo. Authors contribution Daouda KONE: Conceptualization, Methodology. Souleymane TUO: Writing- Original draft preparation. Kolotioloma Alama COULIBALY: Reviewing and Editing. Bi Tra Olivier GORE: Software, Validation. Mariam TRAORE: Visualization, Investigation. Kouakou Bernard DJE: Data curation, Software. Boko AKA:
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