

# SOIL USE AND OCCUPATION OF WIND FARM AGRICULTURAL AREAS

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## Abstract

Wind energy, despite being considered clean and renewable, has negative impacts in the social and environmental scope, significantly altering coastal areas and the interior of Northeast Brazil, this is mainly due to the new land uses arising from the installation of wind towers. Thus, the objective of this research was to analyze changes in land use and occupation of agricultural areas exploited by wind energy, to identify the potential of these agricultural areas for the construction of wind farms and to verify the reconciliation between wind park and agricultural activity. Primary and secondary data collection was used, covering semi-structured interviews and analysis of satellite images. The study area was the municipality of Serra do Mel, located in the State of Rio Grande do Norte, Brazil. The results obtained were processed in the geographic information system QGIS and demonstrated through thematic maps and graphs. It was possible to conclude that the installation of wind farms caused few changes in the classes of land use and occupation, that the agricultural areas of Serra do Mel have great potential for wind energy due to the speed of the winds and the condition of the land and that there is the possibility of reconciliation of agricultural and wind activity.

**Keywords:** Wind Energy; Environment; Remote sensing; Serra do Mel.

## Resumo / Resumen

### USO E OCUPAÇÃO DO SOLO DE ÁREAS AGRÍCOLAS COM ENERGIA EÓLICA

A energia eólica, apesar de ser considerada limpa e renovável, apresenta impactos negativos no âmbito social e ambiental, alterando significativamente as áreas costeiras e do interior do Nordeste Brasileiro, isto se dá, principalmente, pelos novos usos da terra advindos da instalação das torres eólicas. Desta forma, o objetivo desta pesquisa foi analisar as mudanças no uso e ocupação do solo de áreas agrícolas exploradas pela energia eólica, identificar o potencial dessas áreas agrícolas para construção de parques eólicos e verificar a conciliação entre atividade eólica e agrícola. Utilizou-se de coleta de dados primários e secundários, abrangendo entrevistas semiestruturadas e análise de imagens de satélites. A área de estudo foi o município de Serra do Mel, localizado no Estado do Rio Grande do Norte, Brasil. Os resultados obtidos foram processados no sistema de informação geográfica QGIS e demonstrados através de mapas temáticos e gráficos. Foi possível concluir que a instalação de parques eólicos provocou poucas mudanças nas classes de uso e ocupação do solo, que as áreas agrícolas de Serra do Mel possuem ótimo potencial para energia eólica pela velocidade dos ventos e pela condição do terreno e que existe a possibilidade de conciliação da atividade agrícola e eólica.

**Palavras-chave:** Energia Eólica; Meio Ambiente; Sensoriamento Remoto; Serra do Mel.

### USO DEL SUELO Y OCUPACIÓN DE ÁREAS AGRÍCOLAS DE PARQUES EÓLICOS

La energía eólica, a pesar de ser considerada limpia y renovable, tiene impactos negativos en el ámbito social y ambiental, alterando significativamente las zonas costeras y el interior del Nordeste brasileño, esto se debe principalmente a los nuevos usos del suelo derivados de la instalación de torres eólicas. Así, el objetivo de esta investigación fue analizar los cambios en el uso y ocupación del suelo de las áreas agrícolas explotadas por la energía eólica, identificar el potencial de estas áreas agrícolas para la construcción de parques eólicos y verificar la conciliación entre la actividad eólica y agrícola. Se utilizó la recolección de datos primarios y secundarios, cubriendo entrevistas semiestruturadas y análisis de imágenes de satélite. El área de estudio fue el municipio de Serra do Mel, ubicado en el Estado de Rio Grande do Norte, Brasil. Los resultados obtenidos fueron procesados en el sistema de información geográfica QGIS y demostrados mediante mapas y gráficos temáticos. Se pudo concluir que la instalación de parques eólicos provocó pocos cambios en las clases de uso y ocupación del suelo, que las áreas agrícolas de Serra do Mel tienen un gran potencial de energía eólica debido a la velocidad de los vientos y al estado del terreno y que existe la posibilidad de conciliación de la actividad agrícola y eólica.

**Palabras-clave:** Energía Eólica; Medio Ambiente; Detección remota; Serra do Mel.

## INTRODUCTION

The oil crisis, the difficulties caused by conventional energy sources, concerns about the environment, and the damage caused by industrial activities have become increasingly relevant in recent decades and accelerated the development of new energy sources (DANTAS et al., 2019). Lately, there has been a rising worldwide interest in developing and implementing systems of alternative energy sources, which play an important role in reaching the objectives of sustainable development policies related to energy security, reducing environmental impact by restricting the use of fossil fuels and, therefore, mitigating climate change (CÎRSTEA, 2015).

Currently, wind energy has a high profile in the world energy scenario and, likewise, in Brazil, as this renewable energy source is widely available in the territory and has low levels of greenhouse gas emissions. Therefore, wind energy is one promising alternative to reverse the current energy crisis and guarantee national energy security. However, like any other economic activity, it can cause social and environmental impacts that must be analyzed and mitigated (BRANNSTROM et al., 2015; PINTO et al., 2017).

In this context, discussions are being held to make this source truly sustainable, bearing in mind that the process of installing wind turbines has directly affected the environment and the communities who live close to wind farms, generating many socio-environmental conflicts (LOUREIRO et al., 2015). For Armstrong et al. (2016) the effort to produce low-carbon energy has resulted in an unprecedented deployment of onshore wind turbines, representing a significant change in land use for wind power generation.

In the last decades, the wind energy industry has been prominent in the Northeast region of Brazil, where the climatic conditions favor the availability of the raw material, the wind. However, the expansion of wind farms has caused significant environmental changes, ranging from the visual modification of the landscape to the privatization of extensive areas of land (MENDES et al., 2016). According to data from ABEEólica (2018), the three main wind energy producers are located in this region, led by the state of Rio Grande do Norte (RN).

Currently, RN can generate 4.3 GW, with more than 2,000 wind turbines installed, distributed in 159 operational Wind Power Plants. Given that wind energy's total participation in the national energy matrix is around 15.6 GW, RN produces 28% of wind power in the Brazilian territory (ANEEL, 2020). The greatest real estate speculation occurs in the coastal region because, in addition to natural conditions favoring the activity, the locational factor is paramount in this demand. However, currently, RN is going through a process of extending wind farms inland.

The growth of the wind sector is a new productive, economic, and land occupation dynamic in the territories both in the coastal regions and in the interior of the State of RN, however, these areas are also subject to transformation and socio-environmental impacts in the locations where wind farms are being implemented. Thus, geo-technologies are great allies in the effort to minimize the socioenvironmental impacts of wind farms, as they offer important tools in the description, monitoring, and management of space, acting effectively in detecting possible impacts (STORTO and COCATO, 2018).

The environmental impacts caused by anthropization, due to land use, can be mitigated through monitoring, using space-time information, and satellite images to assess the transformations that have occurred in the landscape. Remote sensing techniques and geoprocessing tools have contributed to several studies on the behavior of land cover and use (DORTZBACH et al., 2015).

Thus, it is important to carry out studies that analyze the factors that influence the advance of the processes of land use and occupation and detect changes and their impacts, mainly on the soil, to assist in the planning and management of natural resources. Despite being "clean" energy, wind power can directly affect the communities located around wind farms, which can generate conflicts over new land use and occupation. Thus, the general objective of this research was to analyze the changes in the land use and occupation in the agricultural areas occupied by wind energy, specifically, to identify the potential of these agricultural areas for the construction of wind farms and to verify the possibility of reconciling wind energy and agricultural activity in the municipality of Serra do Mel-RN in the period from 2014 to 2019.

## MATERIAL AND METHODS

### STUDY AREA

This study was carried out in the municipality of Serra do Mel (05°10'39;12.0" latitude south and 37°01'39;44.4" longitude west), in the state of Rio Grande do Norte (Figure 1). The municipality of Serra do Mel was the fruit of a colonization project conceived in 1970, implemented in 1972, but only concluded in 1982. Very quickly, it became a sizable productive center in Rio Grande do Norte, mainly through the cultivation of cashew (*Anacardium occidentale*) and the large-scale export of cashew nuts. In 1988, Serra do Mel attained political autonomy, becoming a municipality in Rio Grande do Norte, the only one in the State originating from a landless worker's settlement (IBGE, 2017).

Serra do Mel has a population of 10,287, of whom 7,589 inhabitants live in the rural area. It has a territorial area of 61,151.04 hectares (IBGE, 2010), which is subdivided into 23 villages, 22 rural villages (community production villages), and one central village (urban area); each village is named after a Brazilian state (Figure 1). The rural villages are made up of 59 plots, usually with 50 hectares (ha) each. In these plots, 15 ha are intended for permanent cashew cultivation, 10 ha for temporary crops, and 25 ha are preserved as native forest (ROCHA, 2013).

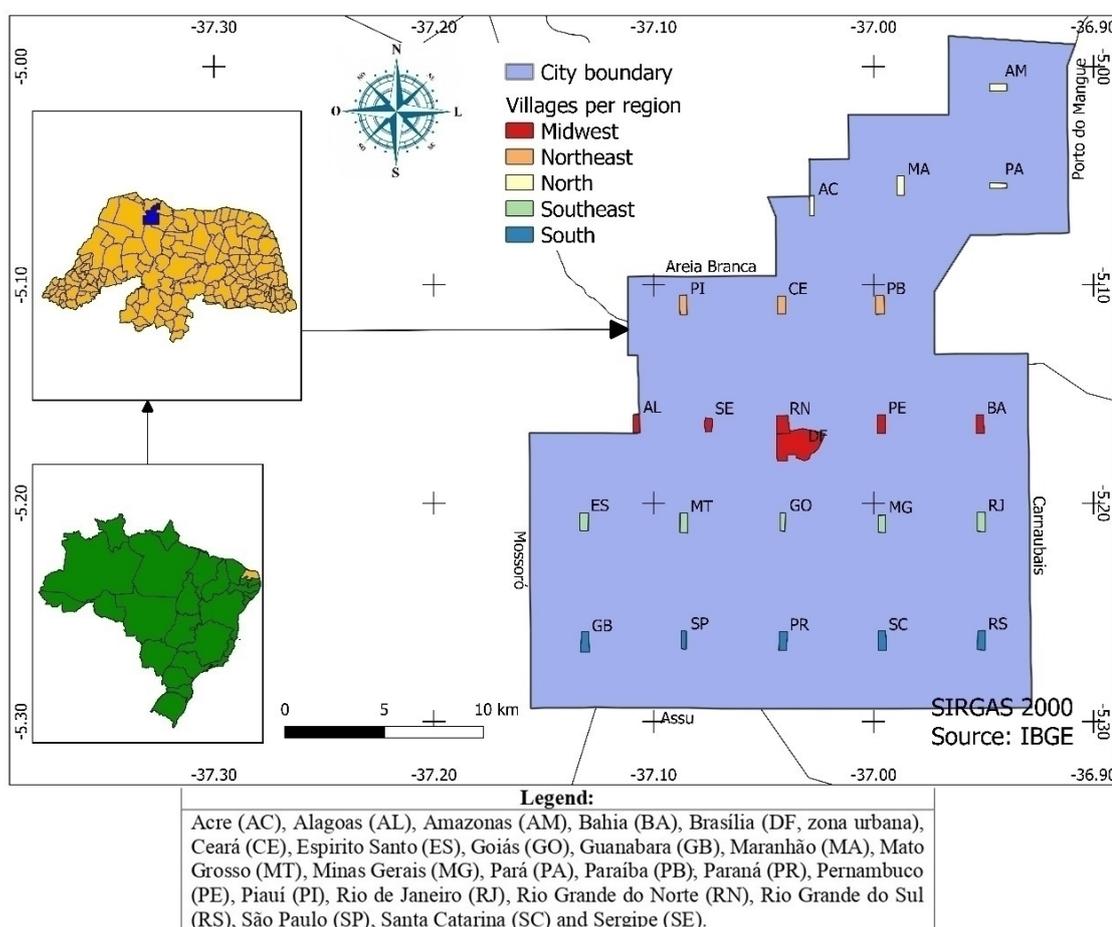


Figure 1 - Map of location and territorial limits, division of towns and regions of the municipality of Serra do Mel. Source: IBGE (2020), prepared by the author.

The municipality's main economic activity is the production and processing of cashew nuts, but since 2015 it has invested in the area of wind energy. Growth in this sector has made Serra do Mel the largest producer of wind energy in the State and the second largest in the country, generating 1,176 MW (ANEEL, 2020).

## DATA COLLECTION AND SAMPLE AREA

This research project is classified as a case study since it consists of collecting and analyzing information about a certain group or community to explain, explore, or describe current phenomena inserted in its particular context. It is a detailed and exhaustive study of a few, or even a single object, resulting in profound knowledge (GIL, 2008).

For data collection purposes, the municipality was divided into five regions as shown in (Figure 1), this division considers the geographic position of the villages and refers to the regional division of Brazil. A total of 220 interviews were conducted and ten landowners (farmers) from each village were interviewed, except for the urban village. All the properties have benefitted or will benefit from wind farms. Farmers were invited to participate in the survey but were not identified. The finite samples proposal (GIL, 2008) and the theoretical saturation criterion (FONTANELLA et al., 2008) were used to define the sampled population.

Data collection was performed using questionnaires with semi-open questions that served as a basis for the interviews, which addressed the interviewee's perception of the impacts generated by wind farms, regarding land use, the possibility of reconciling wind power generation with agricultural activity, as well as their perception of the loss of production caused by the implementation of wind farms. The interviews were carried out in each farmer's lot/residence, for the interviewee's convenience. Furthermore, according to Duarte (2002), the domestic environment makes the respondent more likely to express their ideas and experiences freely.

Data were also collected from the sites of the Ministry of the Environment (MMA), the National Electric Energy Agency (ANEEL), the Brazilian Institute of Geography and Statistics (IBGE), and the Mineral Research and Resources Company (CPRM). This official information was in several formats, including Shapefile, which contains geospatial information. The contents of these archives include municipal boundaries, relief, soils, and roads. They also have information such as the location and capacity of wind farms, wind speeds, and the location of the wind turbines, among other relevant data.

Orbital images were also obtained through the spatial database of the Earth Explorer USGS (United States Geological Survey), which is the United States Department of Soils and Geology, using images from the Landsat 8 OLI/TIRS multispectral satellite. The images were used to produce land use and occupation maps in the municipality of Serra do Mel in the period from 2014 to 2019. This timeframe refers to the year before the construction of the wind farms until the study period. The images were selected in July and August of each year because it is the least cloudy period for capturing images and coincides with the end of the rainy season. An image or a set of images representing the study area were obtained.

## DATA PROCESSING

The data collected in the interviews and websites were systematized and analyzed using the Quantum GIS (QGIS, version 2.18.24 LTR), where the information was processed on the software's attributes table. Next, the data were selected, categorized, and treated to allow a qualitative and quantitative analysis. The SemiAutomatic Classification Plugin (SCP) was used to produce land use and occupation maps.

The images were classified to verify the changes within the area of the municipality of Serra do Mel from 2014 when the process of implantation of wind farms began until 2019. So, the linear contrast was applied to highlight the features of interest, through combinations of bands, colors, and contrasts to extract the maximum information from the images, using the bands 3,4, and 5 of the Landsat -8 sensors. This combination, with two bands in the visible spectrum, and one in the infrared had the best differentiation between vegetation and exposed soil.

As the Serra do Mel has a flat and uniform relief, without surface water reservoirs, three land use classes were defined and mapped: native forest, agricultural land, and exposed soil, represented by the colors dark green, light green, and yellow, respectively. All the maps use the same classification items to compare and analyze the land use and calculate the area of each class. The measurements of the areas are given in hectares (ha) and the percentage of occupation in the territory of Serra do Mel.

## RESULTS AND DISCUSSION

Serra do Mel is located in the “Costa Branca” or Northern Coastal region of RN which has propitious winds and a dry climate. Most of the region’s municipalities are located on the coast and are targets for investments in wind energy and tourism. Unlike other municipalities, Serra do Mel is a transition area between the coast and the sertão, the climate is predominantly semi-arid, with low and irregular rainfall and the vegetation is composed mainly of caatinga. The average altitude in the municipality is 185 m and the maximum is 271 m, and it receives trade winds from the Atlantic Ocean. The relief is in the form of coastal plateaus, with flat topography and low declivity (IBGE, 2017; IBGE, 2020; MMA, 2020; CPRM, 2020). The soil has few obstacles and is largely suitable for agriculture, and anthropization has already occurred in many of the soils in the area. According to the legislation for the implementation of wind farms, the area is in

the low environmental impact class, which facilitates applications for environmental licenses and the construction of the wind parks.

Although strong winds are a good indicator of potential wind farms sites, it is not possible to build a wind farm in all the promising locations, as additional criteria for planning permission may be imposed due to economic or environmental concerns. Cetinay et al. (2017), state that these economic criteria may include the lack or difficulty of transport to the location, the cost of the land, or the distance from the electricity grid. Environmental factors may be proximity to city centers, airports, or forest areas, and high altitudes, among others. Therefore, some locations do not offer satisfactory conditions for the implementation of wind turbines, due to factors such as altitude, relief, and vegetation. The construction of wind farms must obey technical requirements and environmental restrictions, in locations with high quality and quantity winds; they also need a large physical space (ENEVOLDSEN et al., 2019).

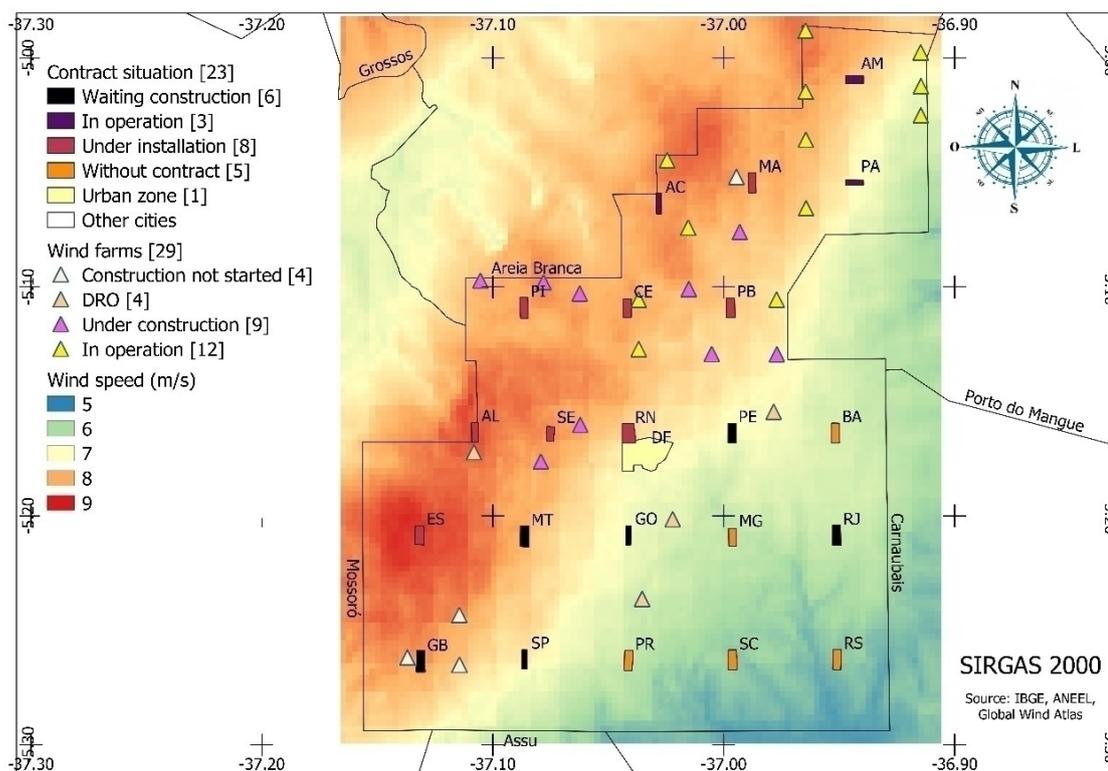


Figure 2 - Wind speed in the Serra do Mel region, the status of the installation wind farms, and contracts by village. Source: D IBGE (2020), ANEEL (2020), Global Wind Atlas (2020), and elaborated by the author.

In addition to Serra do Mel’s physical characteristics, the municipality has a high wind potential.

On average, the winds are between 7 to 9 ms<sup>-1</sup>, so the wind farm installation process took this potential into account in decreasing order of speed (Figure 2). The first wind complex was installed in Amazonas village, which has four parks and a capacity of 93 MW, followed by the wind farms in the villages of Pará with a capacity of 99 MW and Acre with an installed capacity of 58 MW, the two latter are located in the Northern region of the Municipality.

Currently in Serra do Mel there are twelve operational wind farms, a further nine are under construction, four have been authorized but construction has not started, and four have a declaration of the receipt of a grant application (DRO) (Figure 2). Seventeen of the municipality's twenty-two rural villages presently have contracts with wind energy companies and there are five villages without contracts, namely, Santa Catarina and Rio Grande do Sul in the southern region, Minas Gerais in the southeast, and Bahia in the Midwest as shown in Figure 2. Therefore, within the municipality and its regions, there are different situations regarding wind parks, as there are villages without contracts, villages with sites under construction, and villages with operational facilities.

Other situations experienced by farmers are related to the duration of the contracts, the period and the amounts paid for the indemnities, and the percentage of energy generated. The discrepancies between the contract's term and the period of the payment of indemnities for the use of the land cause dissatisfaction. Initially, the indemnification period was equal to the duration of the contract, but currently, the indemnity is only paid during the first eight years of the contract.

From the first installation of wind farms in 2015 until 2019, it is possible to verify the yearly variation of land occupation in the municipality of Serra do Mel and identify the areas of exposed soil, agriculture, and native vegetation (Figure 3). Areas of exposed soil include deforestation, roads, urbanized areas, and wind farms. The native forest is predominantly caatinga vegetation and agriculture mainly involves cashew production.

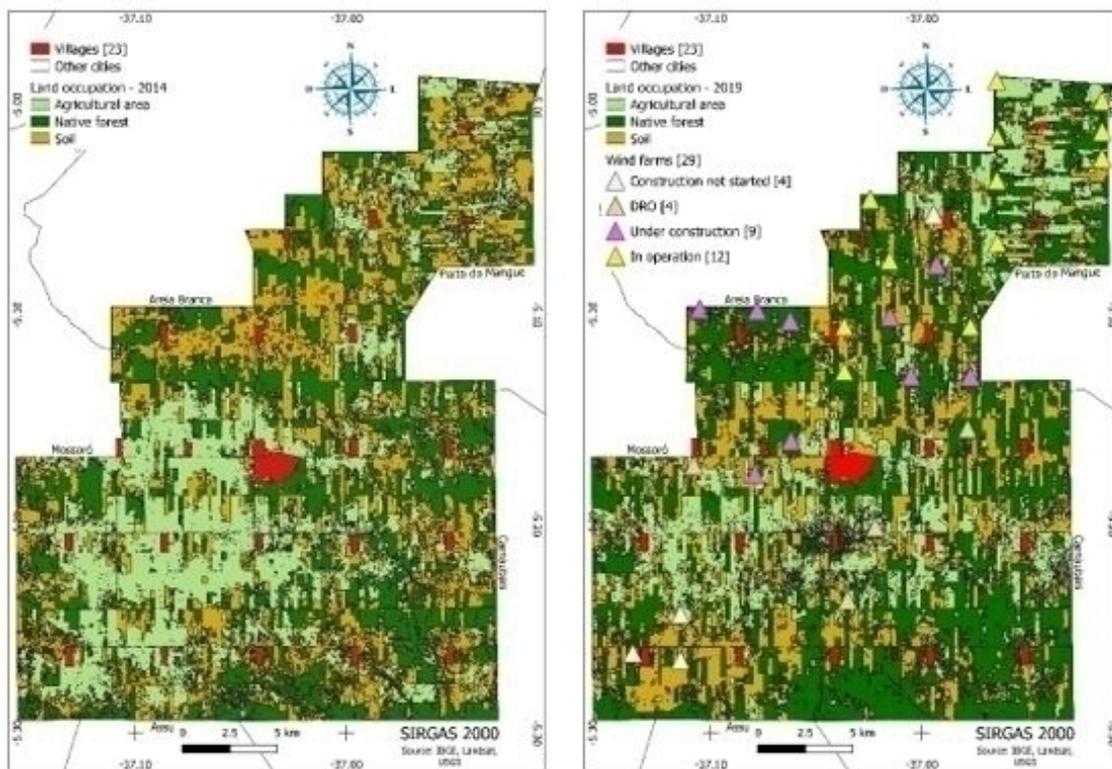


Figure 3 - Changes in land use and occupation in 2014, before the installation of wind farms (A), and in 2019 (B), the current situation in the municipality of Serra do Mel. Source: Landsat 8; USGS; IBGE (2020); prepared by the author

Due to the spatial distribution and organization of land use and occupation in the municipality, from 2014 to 2019, there was a 4% reduction in the area of exposed soil, which is possibly related to the

increase in rainfall in the region, especially in 2017, 2018 and 2019 (Figure 4), which contributed to a 10% increase in the area of native forest. In the same period, there was also a 6% reduction in the agricultural area (Table 1).

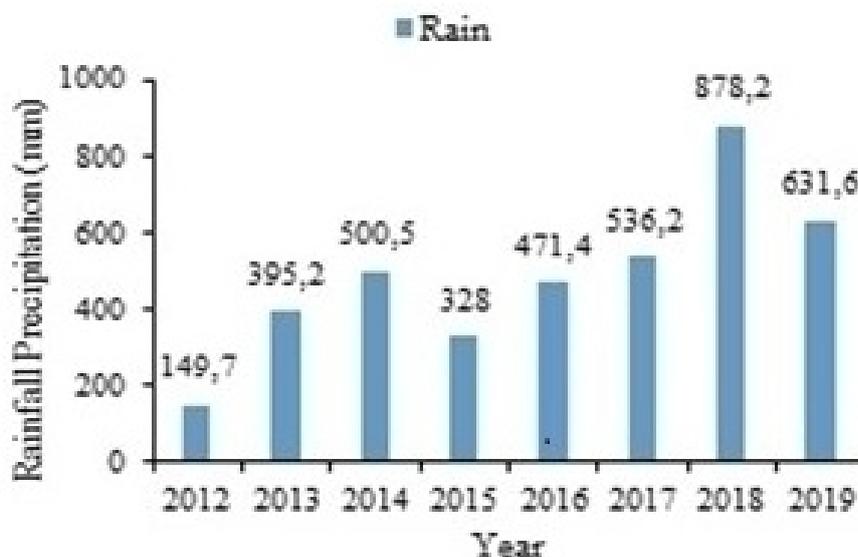


Figure 4 - Precipitation. Source: EMPARN data (2020), prepared by the author.

Year	Class	Area (ha)	Percent	Variation (%)
2014	Exposed soil	22677	37	0
	Agricultural area	21947	36	0
	Native forest	16528	27	0
2015	Exposed soil	21746	35	-2
	Agricultural area	20038	33	-3
	Native forest	19367	32	+5
2016	Exposed soil	25300	41	+6
	Agricultural area	18737	31	-2
	Native forest	17114	28	-4
2017	Exposed soil	23031	38	-3
	Agricultural area	17827	29	-2
	Native forest	20294	33	+5
2018	Exposed soil	18495	30	-8
	Agricultural area	20973	34	+5
	Native forest	21683	36	+3
2019	Exposed soil	20416	33	+3
	Agricultural area	18382	30	-4
	Native forest	22353	37	+1

Table 1 - Changes in area, percentage and annual variation in land use and occupation, in relation to the total area of the Municipality of Serra do Mel from 2014 to 2019, for exposed soil, agricultural areas, and native forest. Source: Prepared by the author.

The farmers believe that the reduction in the agricultural area may have been caused by the mortality of the cashew crop due to the irregular and low rainfall in the years 2012 to 2016 (Figure 4), the pruning of the dry aerial part of the plant to sell the wood, intensifying plant suppression, or even the

suppression of the cropped area to install wind farms. They stated that income from wind energy has not led to a reduction in interest in agricultural activity, as they consider that agriculture is the priority use of a plot of land, and the financial resources from wind energy are an incentive to restructure agricultural areas. However, Katsaprakakis and Christakis (2016), warn that the installation of large wind power generation plants can affect existing activities and change traditional customs.

Five wind farms were installed from 2014 to 2016, there was a 4% increase in the exposed soil area, a 1% rise in the area of native forest, and a 5% reduction in the cultivated area (Table 1). During this period, the construction of new roads, transmission lines, and substations also began. When asked about the use and occupation of the municipality's land by wind farms, the farmers' perception was that in addition to the internal areas for the sites, land use included the opening of new roads and transmission lines in agricultural areas and/or in the villages.

In 2017, another wind farm started operating, however, there was a 3% reduction in the area of exposed soil compared to the previous year (Table 1), possibly due to the growth of native vegetation because of the increase in rainfall (Figure 4). In the same year, the farmers did not report a resumption of agriculture since low cashew production in previous years did not generate sufficient financial resources.

Compared to 2017, in 2018 there was a reduction of the exposed soil of 8%. Native vegetation and agricultural areas increased by 3% and 5%, respectively (Table 1). It is noteworthy in there was regular rainfall in 2018 (Figure 4), and according to the farmers, cashew trees were replanted. However, many farmers carried out this replanting to increase the value of their indemnities, which are higher in areas where there is a loss of cashew crops. On the other hand, the farmers stated that the amount and the location of the lots from which crops will be removed are only revealed when the wind farm is constructed, as the contracts are signed without a definition of the lots involved or how much of each lot will be cut down.

Between 2018 and 2019, there was a 4% reduction in the agricultural area and a 3% increase in the exposed soil area (Table 1), the regular rainfall did not affect the native vegetation area. In 2019, a wind farm started operating and construction began on another four, which started operating in early 2020. Even with the reduction in the agricultural area, farmers did not consider this loss of productive land significant, corroborating Yanaguizawa Lucena and Azevedo Lucena (2019) claim that wind farms do not occupy much physical space, and thus do not compromise land use. Given that only a small percentage of the space is occupied, this suggests that the overall impacts on land use would be low, as many activities can continue (WEISS et al., 2018). However, intense growth in the wind sector can reduce the availability of agricultural areas and cause conflicts over different land use and occupation, as stated by Tabassum-Abassi et al. (2014).

Regarding reconciling agricultural and wind energy activity as set out in the contracts between the interested parties, over 80% of the farmers in all the regions in Serra do Mel stated that the two activities can coexist. They reported that the wind farm installations caused few changes to the plots and did not make agricultural activity unfeasible (Figure 5A). Among the main problems identified by farmers that make it difficult to reconcile the two activities, were the construction of towers in the middle of the lot that hinders the use of agricultural machines, such as tractors, to care for the cashew trees and harvesting. Furthermore, even if the contracts do not prevent farming on the lots, the banks restrict access to rural credit.

SOIL USE AND OCCUPATION OF WIND FARM AGRICULTURAL AREAS

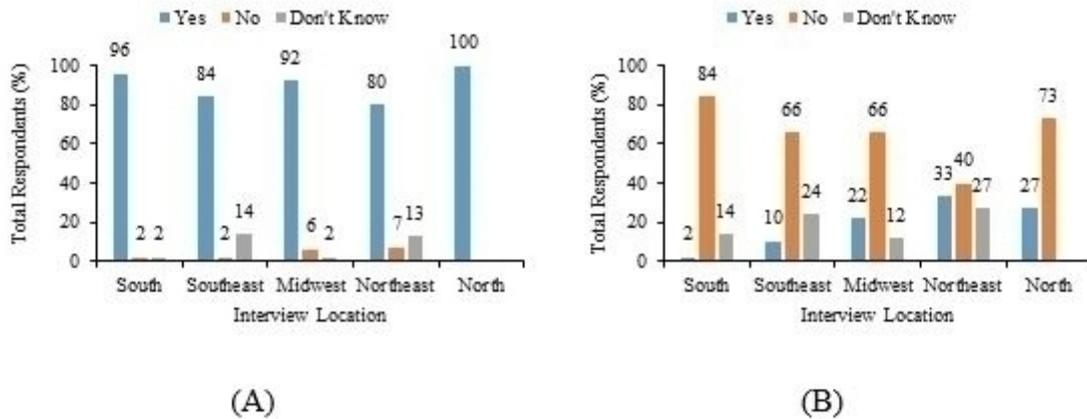


Figure 5 – The perception of the reconciliation of agricultural and wind activity (A) and perception of the loss of production (B) according to the interviewees by region. Source: Prepared by the author.

In Texas-USA, the implementation of wind farms has not prevented other activities (pasture, agriculture, oil extraction) from taking place simultaneously in the same area, with only between 3 to 5% of the productive area lost to wind farms (LOUREIRO et al., 2017). However, the farmers’ use of the area depends on the terms agreed between the parties, so the land occupation and use must be compatible with wind energy. Locations where the economic activities do not overly influence wind behavior, such as livestock and certain types of agriculture, are the most appropriate (YANAGUIZAWA LUCENA and AZEVEDO LUCENA, 2019), however, this process only occurs in areas where land tenure is certain and legal (BRANNSTROM et al., 2017).

In the perception of most farmers, there has not been any loss of production in those cashew trees near the wind farms. Regarding loss of agricultural production, the regions where farmers reported the most losses the Northeast, North, and Midwest, with 33%, 27%, and 22% respectively (Figure 5B) All three regions have power plants in operation and under construction. According to the farmers, the culprit is the dust caused by the machines removing vegetation and opening up access roads to the parks, as well as by the construction company that manufactures the base of the wind turbines. The dust has caused a reduction in cashew and nuts crops, mainly in lots close to wind parks under construction and access roads. When this problem was reported to the parks’ management companies, they began to wet the roads to dampen down the dust, however, no measures have been adopted by the builder of the wind turbine bases. There are no reports of lost production due to the shadow projected by the turbines on the ground during the day or related to possible changes in temperature caused by the wind turbines.

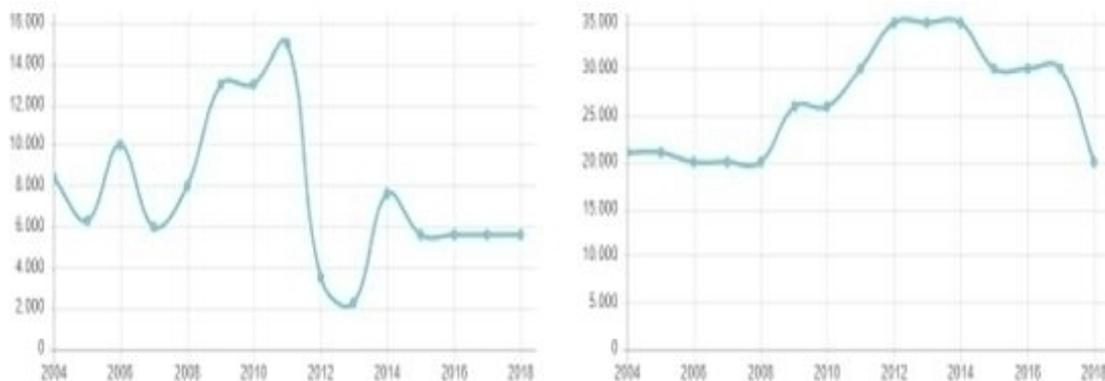


Figure 6 - Quantity of cashew nuts (ton) produced (A), and Area for harvesting (ha) (B) IBGE data (2017)

According to an IBGE survey (2017), there was a fall in the agricultural production of cashew nuts in the municipality from 7,620 tons in 2014 to 5,600 tons in 2018 (Figure 6A). The same study also

showed a decrease in the agricultural area from 35,000 hectares in 2014 to 20,000 hectares in 2018 (Figure 6B).

In a study in northern China, Tang et al. (2017) reported that wind power plants suppressed the water content in the soil and increased water stress, which was directly linked to an 8.9% reduction in gross summer primary production and a 4.0% fall in annual net revenue from primary production. According to Traldi (2018), the huge demand for properties with high wind potential, especially in rural areas, has been found to reduce the areas for agricultural production. Although there is no restriction on the use of properties for agriculture, it is evident that in semi-arid regions those who rent their properties for wind generation end up halting agricultural production.

## CONCLUSION

By evaluating the land use and occupation maps, it was possible to conclude that the installation of wind farms did not cause significant changes in the classes of exposed soil, the agricultural area, and native vegetation in the municipality of Serra do Mel. Thus, the impacts caused by agricultural use and rainfall in the same period were more intense than those caused by the use of land to build wind farms. However, it is clear that in the periods when more wind farms were being built there was an increase in the exposed soil and a simultaneous reduction in the cashew area, indicating that construction occurred more frequently in agricultural areas, which may have influenced the reduction of this class at the time.

Farmers said that it is possible to reconcile agriculture and wind power generation without major repercussions on rural lots and no apparent conflicts between farmers and the company operating the parks. However, some farmers identified losses in the cashew crop caused by the dust generated during the construction of the wind farms, which was confirmed by official IBGE data. Our research also evidenced that the agricultural areas of the Serra do Mel municipality have excellent wind energy generation potential, due to the favorable wind speeds and terrain, which explains the growing expansion of wind energy in the municipality.

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