Vietnam Journal of Earth Sciences, 43(4), 424-443, https://doi.org/10.15625/2615-9783/16443

Vietnam Academy of Science and Technology
Vietnam Journal of Earth Sciences
http://www.vjs.ac.vn/index.php/jse

Investigation and prediction of noise pollution levels from wind turbines: A case study of Nexif Energy Ben Tre wind power plant, South Vietnam

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Received 29 April 2021; Received in revised form 29 July 2021; Accepted 15 September 2021

ABSTRACT

In recent years, the demand for electric power in Vietnam has increased at annual growth rates of 10% to 12%, and the challenge is to promote renewable energy sector. One of these sustainable energy sources is to harness energy from the wind through wind turbines (WTs). In fact, more wind power plants in Vietnam are continuously to be built due to the rapidly growing demand of country's industrialization and modernization process. However, a significant hindrance preventing the widespread use of WTs in Vietnam is the noise they produce, which significantly contributes to the annoyance experienced by residents living near wind farms. The prediction of noise impacts for new wind farms is one of the many aspects of the environmental impact assessment process in Vietnam as well as in the world. In addition, the determination of the 45 dBA noise contour-line is very important because it is the basis for determining the scope of the project impact according to the IFC/WB performance standards and the number of households to be relocated from the project site. The article's main focus is therefore on the estimation and simulation of the acoustical noise produced by 18 WTs during the operation phase of Nexif Energy Ben Tre wind power plant and the background noise levels at the project site have been performed by using a combination of specific study methods such as environmental modeling (iNoise Pro modeling software), mapping and geographic information systems. The obtained results show the importance of using modeling method in quantifying the noise levels generated from 18 wind turbines of the Nexif Energy Ben Tre wind power plant met IFC standard and Vietnamese regulation on noise during day-time, but did not meet IFC standard on noise during night-time. The level of background noise measured during night-time in the project area also did not meet IFC standard. Therefore, the overall cumulative noise level exceeds the IFC standard for residential area (45 dBA only). In addition, the appropriate solutions to reduce noise levels from WTs are also proposed.

Keywords: Wind power; noise modeling; noise pollution; iNoise Pro modeling software.

1. Introduction

Vietnam has a good wind resource for commercial development. An estimate of 3,572 MW wind power can be generated at cost of less than 6 US cents/kWh on an area of 865 km^2 (Nguyen, K.Q., 2007). According to

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the Revised Vietnam Power Plan for the period of 2011-2020, with a vision to 2030 approved by the Prime Minister in Decision No. 428/QD-TTg dated March 18, 2016, the development of wind power is set to total wind power capacity of 800 MW in 2020, 2,000 MW in 2025 and 6,000 MW in 2030. Wind power will account for 0.8% of the total in 2020, about 1% in 2025 and about 2.1% in 2030 (VG., 2016).

Vietnam is currently focusing on mobilizing resources, creating favorable conditions to attract investors who have experience, financial capacity and modern technology in developing wind power plants. This process helps contribute to ensuring national energy security, create a breakthrough to promote socio-economic development as well as realizing Vietnam's green development and environmental protection strategy (VG., 2015). In fact, wind power is a clean energy source that we can rely on for the long-term future, because wind is a source of energy which is non-polluting and renewable, the turbines create power without using fossil fuels, hence free emissions of greenhouse gases or toxic waste.

Wind turbines are built to use natural wind and converting it into electrical energy. These facilities are located in both onshore and near-/offshore locations. A WT creates reliable, cost-effective and pollution-free energy. Operational costs involved in maintaining wind power plants are low and they are generally considered cost effective. Though wind power is long-term benefitable, and being supported by government, significant obstacles preventing wind power development is the noise generated by WTs (S. Oerlemans et al., 2008; Ofelia Jianu et al., 2011). In Vietnam, besides the noise caused by WTs, other obstacles on the policy mechanism and electricity tariff, contribute to slow development of wind power in Vietnam, as of July 2021, only 13 wind power projects with a total capacity of 611.33 MW have been in commercial operation (EVN., 2021).

Most WTs start generating electricity at approximate wind speeds of 4 m/s (10.8 to 14.4 km/h). They generate maximum power at wind speeds of around 12 m/s (43 km/h), and shut down to prevent damage at around 25 m/s (90 km/h) (MoIT/GIZ Energy Support Programme, 2018). And the operation of WTs will generate noise from two main sources (It is depicted in Fig. 1):

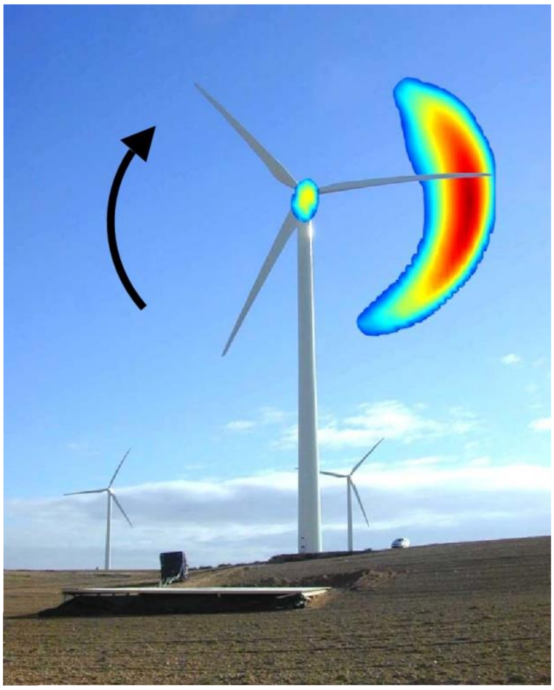


Figure 1. Location of noise sources on a WT

(1) Mechanical noise generated during the working of mechanical components such as gearboxes, generators, drives, cooling fans and ancillary equipment (Rogers et al., 2006).

(2) Aerodynamic noise generated during the interaction of turbine blades and wind turbine towers with blowing air. The level of noise generated by WTs also increases with the wind speed, usually from 4 to 12 m/s (Tickell et al., 2004). The sources of aerodynamic noise can be divided into low-

frequency noise, inflow-turbulence noise, and airfoil self-noise. Low-frequency noise is caused by the aerodynamic interaction between the tower and the blades. Inflow-turbulence noise is caused by the interaction of upstream atmospheric turbulence with the leading edge of the blade, and depends on the atmospheric conditions. Airfoil self-noise is the noise produced by the blade in an undisturbed inflow, and is caused by the interaction between the turbulent boundary layer and the trailing edge of the blade (S. Oerlemans et al., 2008).

Environmental noise is emerging as one of the major public health concerns of the twenty-frst century (WHO, 2009). WTs are a new source of noise in previously quiet rural environments. Environmental noise is a public health concern, of which sleep disruption is a major factor (Nissenbaum M.A. et al., 2012).

In fact, increasing numbers of complaints about sleep disturbance and adverse health effects have been documented (Frey BJ et al., 2007; Pierpont N., 2009; Krogh C., 2011). According to study by Hansen, residents at a distance of 3 km or more from the nearest WT can hear low-frequency noise emitted from wind farms (Hansen et al., 2017).

It has been proven that people exposed to excessive noise will suffer from health problems such as hearing impairment, headaches and fatigue (due to sleep disorders). Extremely high noise exposure may even cause constricted arteries and a weakened immune system (Alberts, 2006). Estimated medical costs incurred by noise are nearly 0.0012 Euro/kWh (AKF-Institute of Local Government Studies, 1996).

In recent years, WTs have been designed and manufactured with much lower noise level, but is still a serious problem because aerodynamic noise from the blades is generally considered to be the dominant noise source, provided that mechanical noise is adequately treated (S. Wagner et al., 1996). Therefore, the article's main focus is on the estimation and simulation of the acoustical noise produced by 18 WTs during the operation phase of Nexif Energy Ben Tre wind power plant and the background noise levels at the project site to determine the scope of the 45dBA noise contour-line and determine the noise safety range according to the IFC/WB performance standards and the national technical regulation on noise of Vietnam (QCVN 26:2010/BTNMT).

2. Materials and Methods

2.1. Study location

The study site is the Nexif Energy Ben Tre wind power plant (capacity of 80 MW) and is located in an area of 2,100 ha in Thanh Hai Commune, Thanh Phu District, Ben Tre Province, Vietnam. It belongs to location No.2 in the Ben Tre Wind Power Development Plan up to 2020, Vision to 2030 (Decision No.2497/QD-BCT dated on March 18, 2015 of the Ministry of Industry and Trade of Vietnam).

The project location is located around 09°49'32'' North latitude; 106°40'19'' East longitude, about 80 km east of Ben Tre city. The project area is in the estuary area, influenced by ebb and flow of the tide. The whole land area planned to build the plant and WTs is sited in the coastal alluvial land in Thanh Hai Commune, Thanh Phu District. This is a coastal alluvial land, with relatively flat seabed. In the boundary of this site, the project arranges the construction of 18 WTs. The project coordinates and boundaries are shown in Table 1, Figs. 2, 3.

Table 1. Offshore project boundary coordinates (VN2000 system, zone 3°)

Coordinates	1	2	3	4	5
Y	599549	600673	601209	609816	607288
X	1086681	1087715	1088573	1086986	1084817

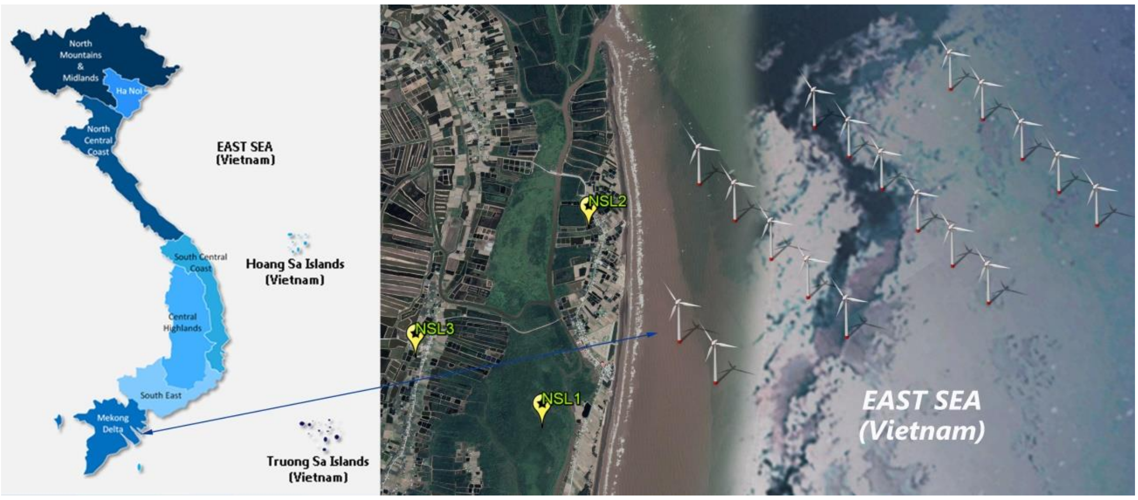


Figure 2. Location of the project in Ben Tre Province, South Vietnam

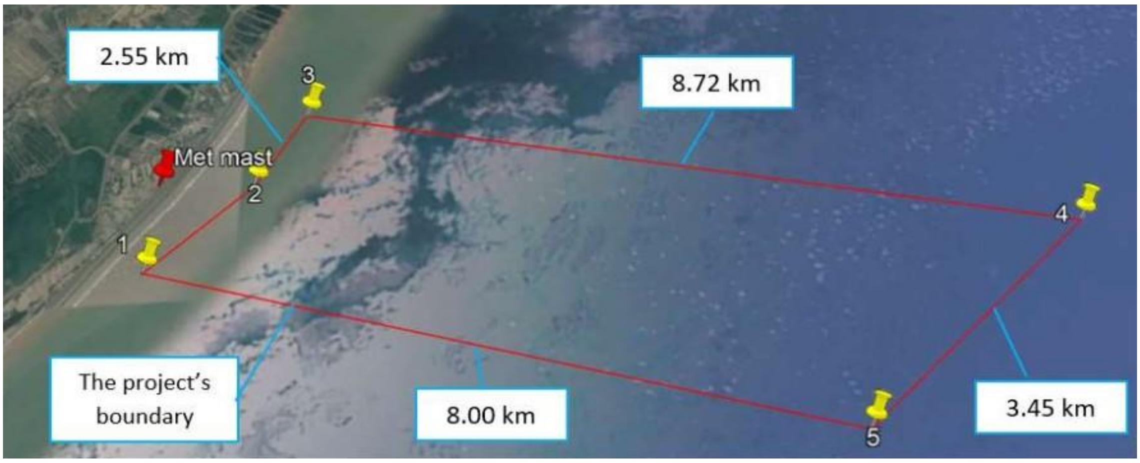


Figure 3. Boundary of Nexif Energy Ben Tre wind power project (PECC5, 2019)

2.2. Database

The input data for the WT noise simulation and calculation model includes: Characteristics of WTs (Table 6); the noise level of WT at rotor axis height (Table 6); coordinates (Table 2) and layout of WTs (Fig. 4); max and average wind speed (Tables 2, 3; Figs. 5, 6, 10), wind directions (Table 4, Fig. 9) and wind frequency (Figs. 7, 8); surface roughness (Table 5); air absorption; ambient air temperature and pressure and humidity (Table 5, Fig. 11); and background noise levels, sound power level (Table 7), rainfall (Fig. 12), etc.

2.2.1. Layout of WTs and natural conditions in the project area

In a year, the winter wind speed (October to April next year) is greater than the summer wind speed (May to September). Therefore, the annual variable pattern has maximum in winter (January - February) and minimum in summer (May - June).

Table 2. Geographic coordinates of WTs under the project (PECC5, 2019)

VN 2000 system, central meridian 105°45', zone 3°					
Turbine	X(m)	Y(m)	Turbine	X(m)	Y(m)
WT1	1088525.810	601222.980	WT10	1087691.888	602730.383
WT2	1087960.737	601326.634	WT11	1087377.749	602794.339
WT3	1087384.934	601422.634	WT12	1087063.907	602854.943
WT4	1086816.955	601519.420	WT13	1086752.843	602919.501
WT5	1086986.349	600812.708	WT14	1086445.762	602980.392
WT6	1087155.743	600105.996	WT15	1086289.920	603011.911
WT7	1086579.701	600193.864	WT16	1086134.078	603043.430
WT8	1088309.608	602598.299	WT17	1085823.931	603106.160
WT9	1088003.267	602668.264	WT18	1088052.815	604006.737

Figure 4. Layout of WTs in the wind power plant (Designed by the author)

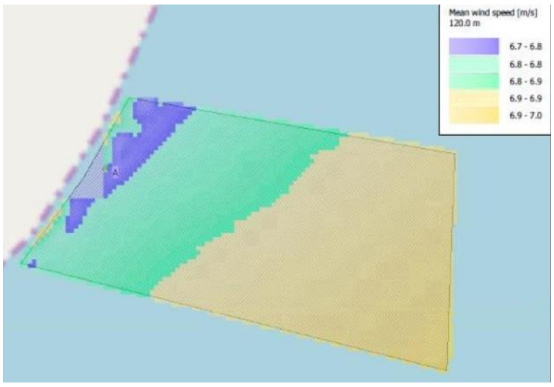


Figure 5. Wind speed map of the project area at an altitude of 120 m (PECC5, 2019)

Table 3. Average monthly wind speed at the wind measuring mast of the project (unit: m/s)

Month / Elev.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Avg.
76m	8.8	9.7	6.5	6.0	4.7	5.0	5.6	6.0	5.1	6.1	7.7	6.3	**6.42**
74m	8.6	9.6	6.5	5.9	4.7	4.7	5.6	6.1	5.2	6.1	7.6	6.2	**6.40**
60m	8.5	9.4	6.3	5.8	4.6	4.6	5.3	5.7	4.8	5.9	7.6	6.2	**6.20**

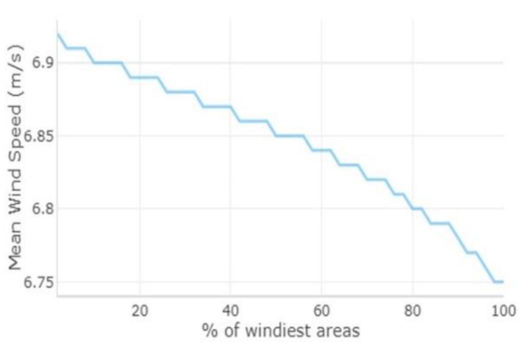


Figure 6. The mean wind speed profile at an altitude of 100 m (https://globalwindatlas.info) (WWA, 2019)

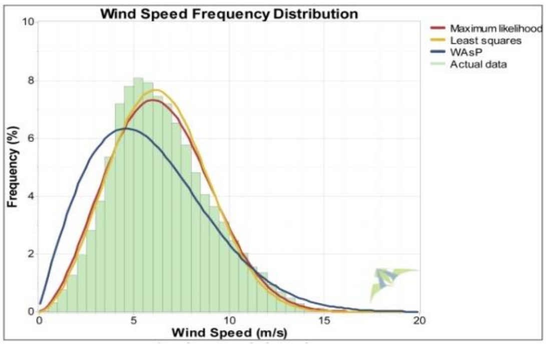


Figure 7. Wind speed frequency distribution (PECC5, 2019)

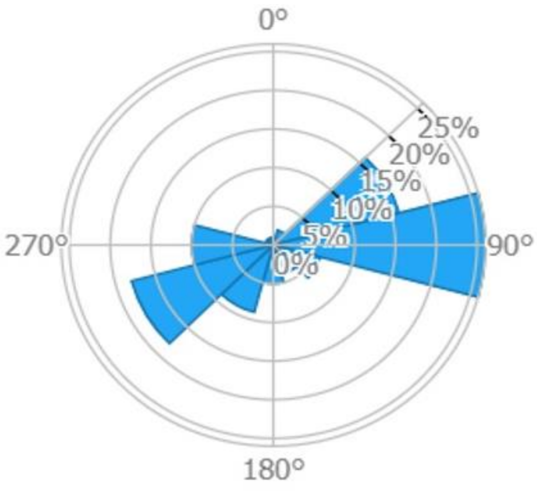


Figure 8. Wind frequency rose (https://globalwindatlas.info) (WWA, 2019)

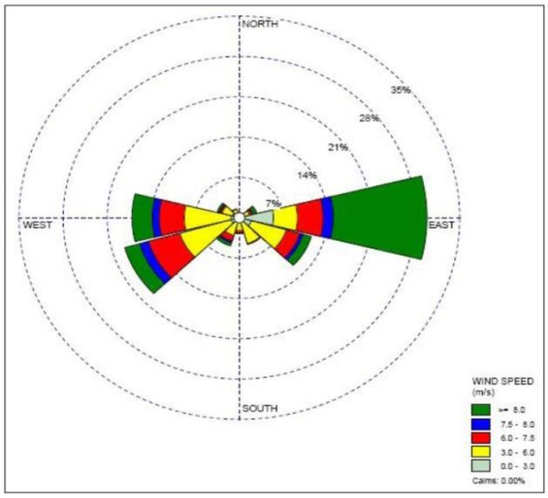


Figure 9. Wind speed rose (PECC5, 2019)

Table 4. Frequency of wind blowing from each direction

Direction	Windless	N	NE	E	SE	S	SW	W	NW
Frequency (%)	21.8	1.5	6.00	28.8	5.1	4.9	16.3	11.1	4.6

Remark: N: North, NE: Northeast, E: East, SE: Southeast, S: South, SW: Southwest, W: West, NW: Northwest (PECC5, 2019)

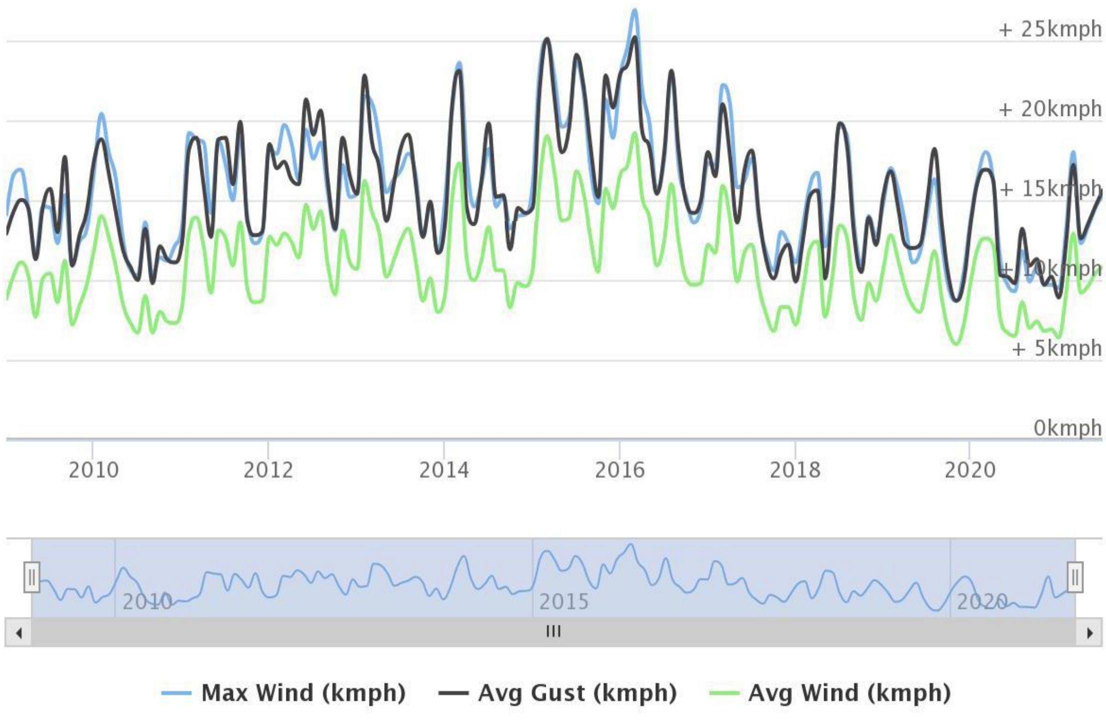
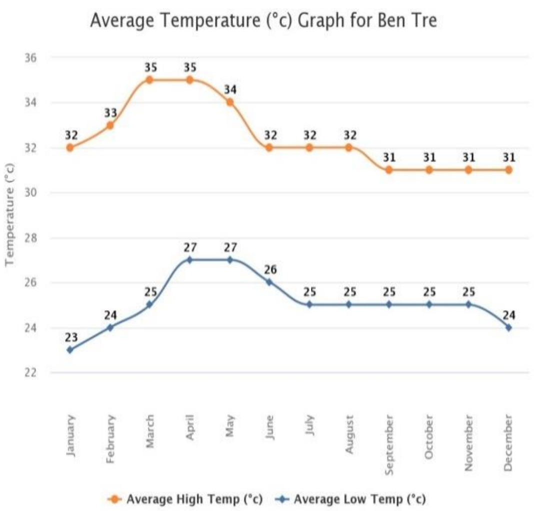


Figure 10. Max and average wind speed and wind gust (km/h) (https://www.worldweatheronline.com/ben-tre-weather-averages/vn.aspx)

Table 5. Summary of measured parameters

No.	Parameters	Value
1	The average annual wind speed at an altitude of 76 m	6.42 m/s
2	The average annual wind speed at an altitude of 120 m	6.7-7.0 m/s
3	Frequency of wind speed at which a turbine starts to generate electricity $v \geq 3$ m/s at 76 m	90 %
4	Factor α	0.196
5	Factor z0	0.168 m
6	Average turbulence intensity at velocity 10 m/s at 76 m	0.07
7	Turbulence intensity category (IEC 61400-1)	C
8	Air density at a height of 76m	1.171 kg/m^3
9	Statistical characteristics of wind data series at 76 m altitude Weibull distribution function	k = 2.19; c = 7.25
10	Average energy density of wind directions at 76 m	273 W/m^2
11	Average air temperature (°C)	27.1
12	Average air humidity (%)	83.6
13	Air pressure (kPa)	101.33
14	Uniform roughness length (m)	0.010



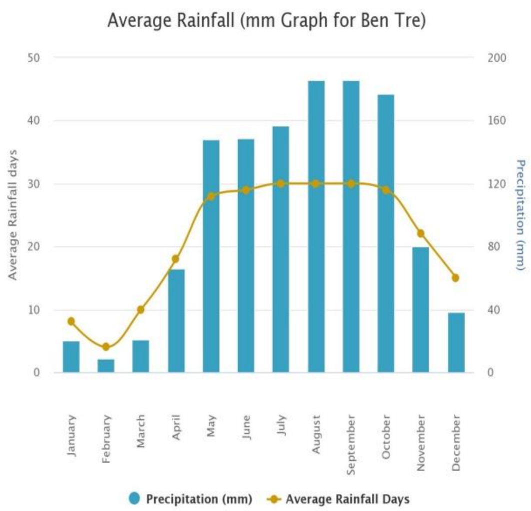


Figure 11. Average high and low temperature (°C) *Figure 12*. Average rainfall days and precipitation (mm) (https://www.worldweatheronline.com/ben-tre-weather-averages/vn.aspx)

Table 6. Brief information of 18 WTs

Type of turbine:	Power capacity (MW)	Hub height (m)	Noise of rotor (dBA)	Diameter (m)	Rotating velocity	Number/ Length of blade (m)	Rotor starts at wind velocity (m/s)	Rated power reaches at wind velocity (m/s)
Siemens Gamesa SG-4.2MW	80	120	106.9	145	15 rpm	3/71	3	11

(Source: Siemens Gamesa's catalogue; PECC5, 2019)

Table 7. Octave band sound power level [dBZ]

Frequency	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	Total sound power level [dBA]
Sound power level (dBA). (SG 4.2MW)	117.4	116.1	111.4	107.1	102.7	101.3	99.7	93.7	82.3	106.9

(Manufacturer-supplied noise specification)

The average wind speed at the height of 76 m in the project area is 6.42 m/s and significant wind speed ranges from 6.7 m/s to 7.0 m/s at the height of 120 m (Table 5), with the prevailing wind direction being the East. Wind speed has been extrapolated to calculation height using IEC profile shear (H_0 = 0.05 m).

Vietnam is located in a tropical monsoon region and it is divided into seven climate sub-regions and the project area in Ben Tre province belongs to the climate sub-region of South Vietnam. The annual average air temperature is about 27.1°C, the observed highest temperature is 36.5°C and the observed lowest temperature is 17.2°C. In general, the underestimation of temperature is prominent in the Northwest and South Central in the late winter and in Central Highlands and Southern Vietnam in Spring (Nguyen Thi Tuyet et al., 2019). However, the temperature variability among the months of the year in the project area does not differ greatly.

The monthly average high and low air temperature, and monthly average rainfall days and precipitation are as follows (Figs. 11, 12):

The rainy season usually starts from May and ends in October. The largest monthly rainfall is in September, the dry season from November to April next year. The annual rainfall in the project area is average, about 1,545 mm/year. Six months of the rainy season accounts for about 87% of the annual rainfall, the dry months account for only about 13% of the annual rainfall. In Ben Tre province, the months with the large rainfall are June, July, August and September, these months are also the months with heavy rain days.

The project area is affected by marine climate, so the annual total number of hot days is much lower than the North Central sub-region. In fact, the number of hot days in the North Central sub-region ranges widely from 1.8 to 85.1 days between 1980 and 2013. In comparison with the other sub-regions of Vietnam, North Central sub-region has a large number of hot days with over 40 days/year (Pham Thi Ly et al., 2019).

According to the results of the regional study, during 57 years from 1961-2017 a total of 19 storms hit the coast of the project area. The thunderstor season usually starts from May and ends in November, every year the area has 50-60 days of thunderstorms.

2.2.2. Characteristics of WTs

Nexif Energy Ben Tre wind power plant consists of 18 Siemens Gamesa SG 4.2-145 WTs, each of which has a capacity of 4.2 MW. The project wind turbines have a hub height of 120 m (PECC5, 2019). Wind turbines are manufactured by Siemens Gamesa (Spain) with a noise level at rotor axis of 106.9 dBA (Based on the manufacturer's catalogue).

2.2.3. Receptors

In fact, there is no household settlement within 2 km of any of the WT location of the project. However, we have selected three locations (scattered) in the range of wind turbine impact (NSL1/N1, NSL2/N2, NSL3/N3) representative by noise sensitive site. The noise sensitive locations (NSLs) considered in this study are as the Fig. 2 and Fig. 13.

Figure 13. Location of three noise monitoring location

- NSL1 (N1): It is located at coordinates 9°49’43.0’’N, 106°38’51.4’’E, behind Mr. Pham Van Tien’s house, 85 m from the communal road and 291 m from the Bien Dua beach.
- NSL2 (N2): It is located at Tay Do beach and restaurant (coordinates: 9°50’34.3’’N, 106°39’40.7’’E).
- NSL3 (N3): It is the farthest site from Con Bung Beach (2.5 km, in the Southeast direction) and it is not located in Thanh Hai commune (coordinates: 9°50’27.1’’N, 106°38’26.9’’E).

2.2.4. The background noise level measured in the plant area

The levels of daily average background noise measured in the project area before construction of Nexif Energy Ben Tre wind power plant ranges from 50-53 dBA. In the day-time, the noise level is commonly measured in the range of 49-54 dBA. The noise levels at observated sites were found to increase in the evening. The highest noise levels were recorded of 54.1 dBA at around 22-23 PM. Therefore, the noise levels at night-time did not meet IFC standard noise for residential area (45 dBA for night-time only) (SESTEV, 2019).

According to the Environmental, Health and Safety guidelines of IFC/WB: Noise level guidelines for residential, institutional and educational receptors in day-time (07h-22h) is 55 dB(A) and night-time (22h-7h) is 45 dB(A).

Because it is sheltered by mangrove forest (Fig. 14), households living behind the mangroves forests are less affected by noise from the waves and sea breeze. Mangrove forests are a spectacular ecosystem, occupying the boundary between land and sea. In most areas, mangroves forests are important filters of pollutants from atmospheric deposition, continental run-off and tidal currents (Tran Trong Hung et al., 2019).

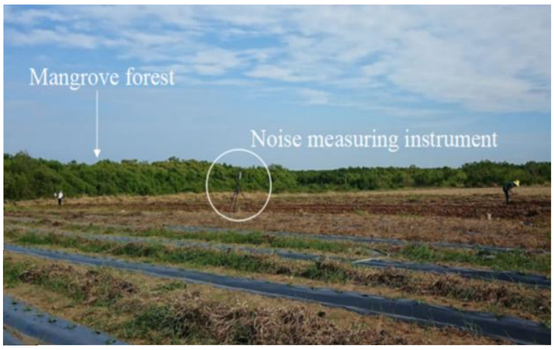


Figure 14. Noise monitoring site (N3)

In general, no landscape is ever completely quiet. The wind from the sea is considered as a main noise sources before starting construction of Nexif Energy Ben Tre wind power plant. Besides, dogs, chickens, birds, traffic, and domestic activities are considered as the secondary noise sources.

2.3. Method for modeling noise and calculating resonance noise

The purpose of the study is to estimate

noise levels from the wind power plant within the context of regulatory requirements specified of Vietnam and IFC standards. In general, to demonstrate regulatory compliance, Vietnam's environmental regulation and IFC standard require that cumulative noise levels at relevant receptors be compared to a mandated permissible sound level limit. Accordingly, cumulative noise levels should be calculated as the sum of an ambient sound level meant to represent the contribution from natural noise sources, non-industrial noise sources, and existing industrial facilities such as the Nexif Energy Ben Tre wind power plant, etc.

The environmental noise prediction iNoise Pro software was used to calculate and model noise emissions from 18 WTs of Nexif Energy Ben Tre wind power plant. We have chosen Inoise Pro software because it is quality assured for calculating noise from WTs and other activities in the environment. The calculations are based on the ISO 9613-1/2 method (ISO 9613-1&2:1993(en)., 1996a, b) and the recommendations of the new quality standard ISO 17534-3 (ISO 17534-3., 2015) for calculating the downwind noise levels and the long-term noise levels and the short-time LAeq based on wind direction, wind speed and stability class. The ISO 9613 standard from 1996 is the most used noise prediction method worldwide. Many countries refer to the ISO 9613 in their noise legislation. However, the ISO 9613 standard does not contain guidelines for quality assured software implementation, which leads to differences between applications in calculated results. In 2015 this changed with the release of ISO/TR 17534-3. This quality standard gives clear recommendations for interpreting the ISO 9613 method.

In order to consider worst case scenario (with strong wind conditions), we have been assumed that the WTs are operational at standardised wind speed of ≥ 7 m/s at 10 m height (i.e. about 9 m/s at hub height). Operating of WTs with 100% usage scenario was modelled to cover the operation phase of the Project. In addition, to represent a worst-case scenario for the assessment, all WTs were assumed to be operating simultaneously and for 24 hours. Noise generation had been considered at the hub height of 120 m above ground.

Local terrain roughness has been considered for putting noise sources as well as receptors in the model. It has been assumed that the noise sensitive receptors are always in downwind direction to consider the worst case scenario. The geo-profile of the area has been considered to define the area types and relative roughness and surface hardness in order to consider the surface absorption and reflection.

Based on the available information from the turbine manufacturer, following are the noise generation due to the WTs:

Noise emitted from the WTs will increase with hub height wind speed (Table 8), until hub height wind speed reaches 9 m/s. According to the design of the wind turbine manufacturer, the noise emission from the WTs of the plant will remain constant (106.9 dBA) for all hub height wind speeds greater than or equal to 9 m/s up to 25 m/s.

Furthermore, the shape of the noise emissions spectrum will not change for hub wind speeds greater than or equal to 9 m/s.

Also according to the design of the manufacturers, all wind turbines have to be storm-proofed and therefore the wind turbines will stop working when a storm or tornado occurs with a wind speed of 25 m/s (90 km/h) or more to prevent damage.

Table 8. Noise generation from WTs

Wind velocity at 10 m height (m/s)	Noise generation [dB(A)] at Hub height	Wind velocity at Hub height (m/s)	Noise generation [dB(A)] at Hub height
3.0	95.8	5.0	97.8
4.0	96.8	6.0	99.7
5.0	101.9	7.0	103.2
6.0	104.6	8.0	106.2
7.0	106.9	9.0	106.9
8.0	106.9	10.0	106.9
9.0	106.9	11.0	106.9
10.0	106.9	12.0	106.9
11.0	106.9	13.0	106.9
12.0	106.9	Up to cut-out	106.9

(Source: Based on manufacturer's documents)

Predicted noise levels at receptors: The predicted noise levels within the study area at 3 receptors during day-time and night-time with cloudy conditions and with strong wind conditions.

According to the ISO 9613-1/2 method, each WT is a noise source and is considered a point source and assuming hemispherical propagation (i.e., the radiation of sound, in all directions). The sound pressure level at a position is determined by subtracting the sound pressured drop from the external elements from the noise source (WT) in the octave frequency range.

Based on the ISO 9613 - 1/2 method, noise levels will be calculated as follows:

$$L_{lt,per} = L_{dw} - C_{m,per} - C_{t,per} \quad (1)$$

$$L_{dw} = L_W + D_c - A \quad (2)$$

$L_{lt,per}$: Long-term average octave (or 1/3-octave) SPL during the evaluation period in dB

L_{dw}: Equivalent continuous downwind octave (or 1/3-octave) SPL in dB

$C_{m,per}$: Meteorological correction during the evaluation period in dB

$C_{t,per}$: Correction for the active time of the source during the evaluation period in dB

L_W: Sound power level in dB(A) per octave (or 1/3-octave), re 1 pW

D_c: Directivity correction in dB

A: Attenuation (octave-band) in dB per octave (or 1/3-octave)

The attenuation A is calculated as follows:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{fol} + A_{site} + A_{hous} \quad (3)$$

A_{div}: Geometrical divergence in dB

A_{atm}: Atmospheric absorption in dB/octave (or 1/3-octave)

A_{gr}: Terrain effect in dB/octave (or 1/3-octave)

A_{bar}: Screening in dB/octave (or 1/3-octave)

A_{fol}: Attenuation due to foliage in dB/octave (or 1/3-octave)

A_{site}: Attenuation due to installations on an industrial site in dB/octave (or 1/3-octave)

A_{hous}: Attenuation due to housing in dB

The resonant noise level of the whole wind power plant is calculated as follows:

$SPL_{Wind\ farm} = \sum(SPL_{Turbine}$ within a radius of 3 km from the wind turbine).

According to study results by the Danish Wind Industry Association (Table 9), assuming that sound reflection and absorption (if any) cancel one another out, then the sound level decreases by approximately 6 dB(A) [=10*log10 (2)] every time we double the distance to the sound source. Two identical sound levels added up will give a sound level +3 dB(A) higher, and 4 turbines will give a sound level 6 dB(A) higher, and 10 turbines will give a level 10 dB(A) higher, etc.

Table 9. Sound level by distance from a noise source

Distance (m)	Sound level change dB(A)	Distance (m)	Sound level change dB(A)	Distance (m)	Sound level change dB(A)
9	-30	100	-52	317	-62
16	-35	112	-53	355	-63
28	-40	126	-54	398	-64
40	-43	141	-55	447	-65
50	-45	159	-56	502	-66
56	-46	178	-57	563	-67
63	-47	200	-58	632	-68
71	-49	224	-59	709	-69
80	-50	251	-60	795	-70
89	-51	282	-61	892	-71

(Source: Danish Wind Industry Association)

The data processing steps about noise sources and noise propagation is as follows (Fig. 15):

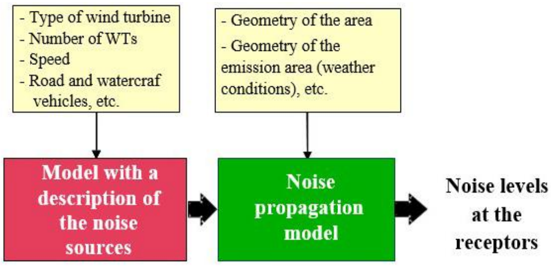


Figure 15. Data processing and noise propagation

The process is divided into two main steps: data processing and noise propagation.

- *Data processing* relates to the noise sources, with a distinction between the wind turbines and road vehicles and watercraft vehicles as noise sources. All the sources are described as physical noise sources with a total sound power, directivity and a certain position.

- *Noise propagation*: The total noise attenuation is primarily composed of geometrical divergence, atmospheric absorption and excess attenuation. If reflected propagation paths occur, a correction is made for the effectiveness of each successive reflection. The attenuation is computed according to ISO 9613-1 must be a function of meteorological conditions, determined by wind speed and air temperature gradients for each specific direction as well as ambient pressure and relative humidity, etc.

3. Calculation results

The results of applying Inoise Pro software to estimate the noise levels and sound power from a WT (Fig 16, Table 10) as well as resonant noise levels from 18 WTs of Nexif Energy Ben Tre wind power plant and background noise levels are presented below (Table 11, 12; Figs. 17, 18). Noise levels were predicted during operation phase with strong wind conditions and most downwind conditions.

(1) Noise levels emitted from each wind turbine;

(2) Calculation results of cumulative noise levels for noise sensitive areas;

When calculating noise levels at receptors, the ISO 9613-2 algorithm used the input data to account for four noise attenuation mechanisms: (i) Geometric divergence; (ii) Atmospheric absorption; (iii) Ground absorption; and 4) Screening by barriers.

Predicted noise levels at noise sensitive receptors during operation phase with strong wind conditions and downwind conditions. Results are presented in the following tables:

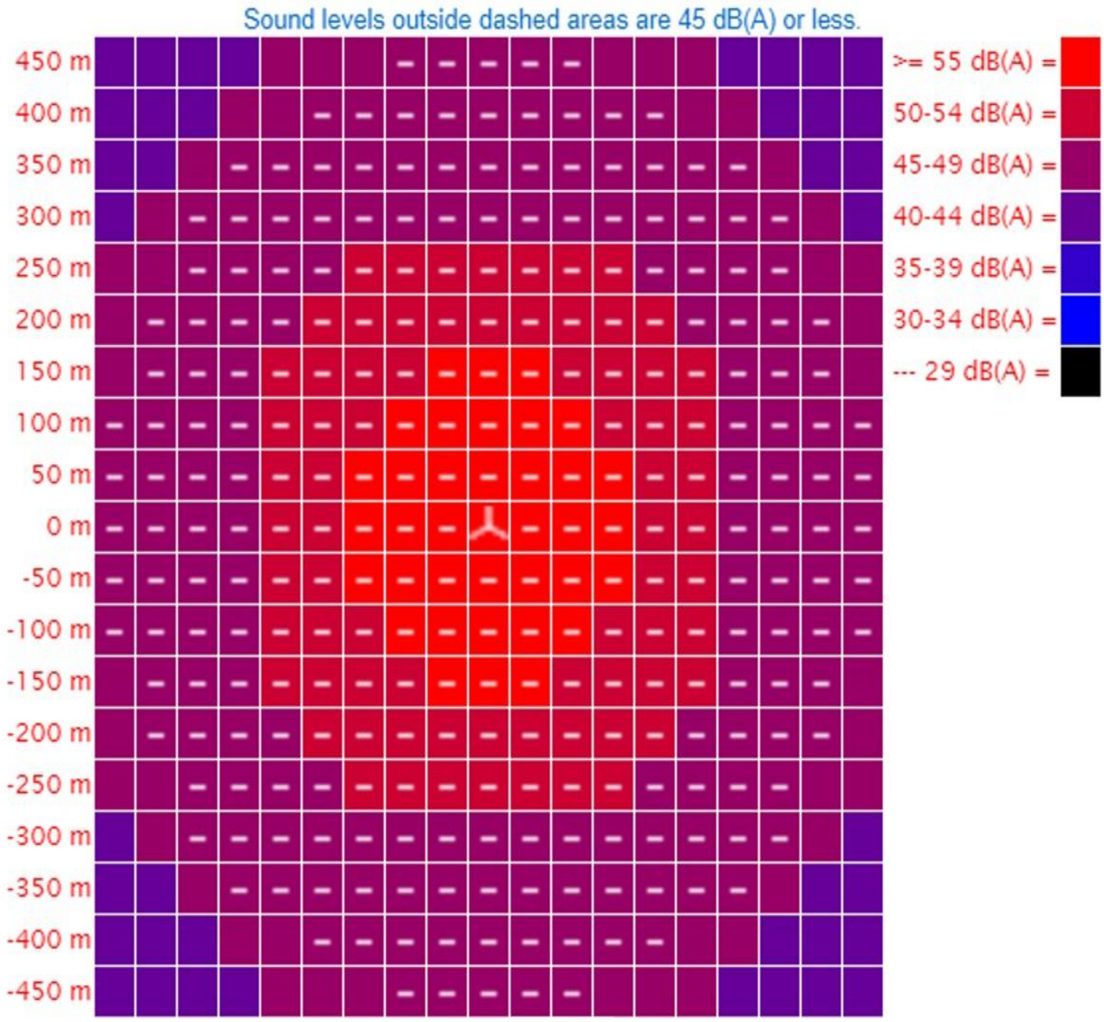


Figure 16. Noise levels around the SG 4.2-145 wind turbine to the ground

Table 10. Noise variation by distance to the rotor axis of wind turbine to the ground

Noise source at rotor axis (dBA)	Distance from the source (m)	Resulting dB(A) noise level	Sound Power W/m^2
106.9	50	65.03	0.0000031831
	100	59.01	0.0000007958
	150	55.49	0.0000003537
	200	52.98	0.0000001989
	250	51.05	0.0000001273
	300	49.47	0.0000000884
	350	48.13	0.0000000650
	400	46.98	0.0000000497
	450	45.94	0.0000000393
	500	45.03	0.0000000318

(Calculated results according to the instruction of the Danish Wind Industry Association)

Table 11. Calculation results of cumulative noise levels at 3 noise sensitive site (Day-time)

Name	Coordinates	Receptor height (m)	Wind speed (m/s)	Direction (°)	Predicted noise level from WTs (dBA)	Predicted cumulative noise level (dBA)
NSL1	9°49’43.0’’N; 106°38’51.4’’E	1.5	7.0	0.0	48.2	52.4
NSL1		1.5	7.0	30.0	48.2	52.4
NSL1		1.5	7.0	60.0	48.1	52.3
NSL1		1.5	7.0	90.0	48.0	52.2
NSL1		1.5	7.0	120.0	47.8	52.0
NSL1		1.5	7.0	150.0	47.6	51.8
NSL1		1.5	7.0	180.0	47.3	51.5
NSL1		1.5	7.0	210.0	47.4	51.6
NSL1		1.5	7.0	240.0	47.6	51.8
NSL1		1.5	7.0	270.0	47.8	52.0
NSL1		1.5	7.0	300.0	47.9	52.1
NSL1		1.5	7.0	330.0	48.2	52.4
NSL2	9°50’34.3’’N; 106°39’40.7’’E	1.5	7.0	0.0	49.1	53.3
NSL2		1.5	7.0	30.0	49.0	53.2
NSL2		1.5	7.0	60.0	48.9	53.1
NSL2		1.5	7.0	90.0	48.8	53.0
NSL2		1.5	7.0	120.0	48.6	52.8
NSL2		1.5	7.0	150.0	48.5	52.7
NSL2		1.5	7.0	180.0	48.3	52.5
NSL2		1.5	7.0	210.0	48.3	52.5
NSL2		1.5	7.0	240.0	48.4	52.6
NSL2		1.5	7.0	270.0	48.6	52.8
NSL2		1.5	7.0	300.0	48.7	52.9
NSL2		1.5	7.0	330.0	48.9	53.1
NSL3	9°50’27.1’’N; 106°38’26.9’’E	1.5	7.0	0.0	45.3	49.6
NSL3		1.5	7.0	30.0	45.2	49.5
NSL3		1.5	7.0	60.0	45.2	49.5
NSL3		1.5	7.0	90.0	45.1	49.4
NSL3		1.5	7.0	120.0	45.0	49.3
NSL3		1.5	7.0	150.0	45.0	49.3
NSL3		1.5	7.0	180.0	44.9	49.2
NSL3		1.5	7.0	210.0	44.8	49.1
NSL3		1.5	7.0	240.0	45.1	49.4
NSL3		1.5	7.0	270.0	45.1	49.4
NSL3		1.5	7.0	300.0	45.2	49.5
NSL3		1.5	7.0	330.0	45.3	49.6

- IFC/WB EHS Guidelines: Noise level guidelines for residential; institutional and educational receptors in day-time (07h-22h) and night-time (22h-7h) as 55dB(A) and 45dB(A) respectively.
- According to the national technical regulation on noise of Vietnam (QCVN 26:2010/BTNMT), the noise created by the production, construction, trading, service provision, and life must not exceed the permissible noise limits (dBA): 1) For special areas: 55 dBA from 6:00 to 21:00 and 45 dBA from 21:00 to 6:00; 2) For usual areas: 70 dBA from 6:00 to 21:00 and 55 dBA from 21:00 to 6:00.

Table 12. Calculation results of cumulative noise levels at 3 noise sensitive site (Night-time)

Name	Coordinates	Receptor height (m)	Wind speed (m/s)	Direction (°)	Predicted noise level from WTs (dBA)	Predicted cumulative noise level (dBA)
NSL1	9°49'43.0''N; 106°38'51.4''E	1.5	7.0	0.0	48.8	53.3
NSL1		1.5	7.0	30.0	48.8	53.3
NSL1		1.5	7.0	60.0	48.7	53.2
NSL1		1.5	7.0	90.0	48.5	53.0
NSL1		1.5	7.0	120.0	48.3	52.8
NSL1		1.5	7.0	150.0	48.0	52.5
NSL1		1.5	7.0	180.0	47.8	52.3
NSL1		1.5	7.0	210.0	47.9	52.4
NSL1		1.5	7.0	240.0	48.1	52.6
NSL1		1.5	7.0	270.0	48.3	52.8
NSL1		1.5	7.0	300.0	48.5	53.0
NSL1		1.5	7.0	330.0	48.7	53.2
NSL2	9°50'34.3''N; 106°39'40.7''E	1.5	7.0	0.0	49.6	54.1
NSL2		1.5	7.0	30.0	49.5	54.0
NSL2		1.5	7.0	60.0	49.4	53.9
NSL2		1.5	7.0	90.0	49.3	53.8
NSL2		1.5	7.0	120.0	49.1	53.6
NSL2		1.5	7.0	150.0	49.0	53.5
NSL2		1.5	7.0	180.0	48.8	53.3
NSL2		1.5	7.0	210.0	48.8	53.3
NSL2		1.5	7.0	240.0	48.9	53.4
NSL2		1.5	7.0	270.0	49.1	53.6
NSL2		1.5	7.0	300.0	49.2	53.7
NSL2		1.5	7.0	330.0	49.4	53.9
NSL3	9°50'27.1''N; 106°38'26.9''E	1.5	7.0	0.0	45.7	50.2
NSL3		1.5	7.0	30.0	45.6	50.1
NSL3		1.5	7.0	60.0	45.6	50.1
NSL3		1.5	7.0	90.0	45.5	50.0
NSL3		1.5	7.0	120.0	45.4	49.9
NSL3		1.5	7.0	150.0	45.4	49.9
NSL3		1.5	7.0	180.0	45.3	49.8
NSL3		1.5	7.0	210.0	45.2	49.7
NSL3		1.5	7.0	240.0	45.5	50.0
NSL3		1.5	7.0	270.0	45.5	50.0
NSL3		1.5	7.0	300.0	45.6	50.1
NSL3		1.5	7.0	330.0	45.7	50.2

- IFC/WB EHS Guidelines: Noise level guidelines for residential; institutional and educational receptors in day-time (07h-22h) and night-time (22h-7h) as 55dB(A) and 45dB(A) respectively.
- According to the national technical regulation on noise of Vietnam (QCVN 26:2010/BTNMT), the noise created by the production, construction, trading, service provision, and life must not exceed the permissible noise limits (dBA): 1) For special areas: 55 dBA from 6:00 to 21:00 and 45 dBA from 21:00 to 6:00; 2) For usual areas: 70 dBA from 6:00 to 21:00 and 55 dBA from 21:00 to 6:00.

According to the above simulated and calculated results (Table 11, 12; Figs 17, 18), during the day-time, the resonant noise level generated from 18 WTs is from 44.8 to 49.1

dBA, which is expected to increase to 45.2 - 49.6 dBA in the evening due to stronger wind speeds at night-time. When there is a noise resonance between 18 turbines and the background noise, the cumulative noise level increases from 49.1 to 53.3 dBA during day-time and from 49.7 to 54.1 dBA during night-time.

(3) Assessing the accuracy of predictive model.

To assess the accuracy of the ISO 9613-1/2 method and the resonant noise calculation results using Inoise Pro software, we have measured noise levels for 48 hours at 3 receptors (NSL1, NSL2 and NSL3) after the wind power plant came into operation. The results showed that the difference in noise level values ranged from 0.01 to 0.05 dBA (Table 13, Fig. 19).

From Table 13 showed that, the results calculated by ISO 9613-2 method through the use of Inoise Pro software are reliable.

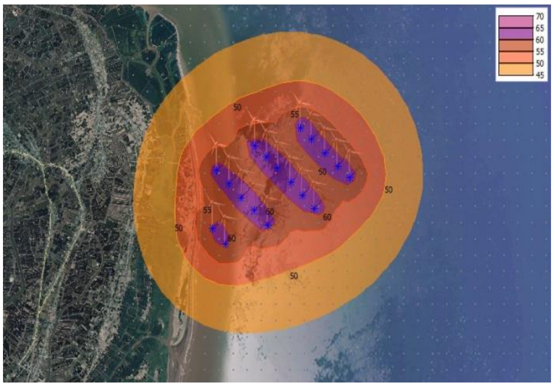


Figure 17. Resonant noise levels from 18 WTs of the wind power plant

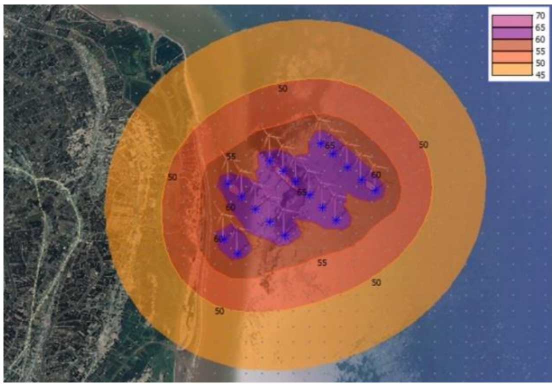


Figure 18. Resonant noise levels from 18 WTs of the wind power plant and background noise

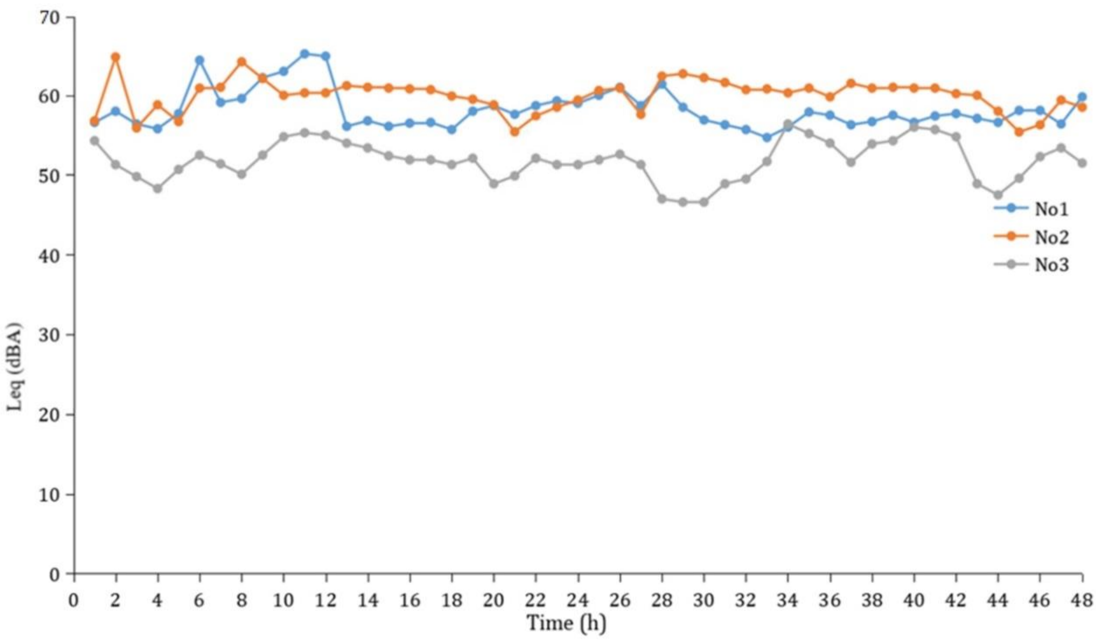


Figure 19. Hourly observed Leq (dBA) at three monitoring locations

Table 13. Verification of software application results

Test	Technical report of ISO/TR 17534-3 - Annex for ISO 9613-2		
Calculation method	Recommendations for quality assured implemenation of ISO 9613-2 according to ISO/TR 17534-3		
Receptor name	Observed real results {dB(A)}	Software calculation result {dB(A)}	Result inside tolerances (±0.05)
NSL1	52.43	52.40	Yes
NSL2	53.35	53.30	Yes
NSL3	49.61	49.60	Yes

4. Discussions

4.1. For the noise levels generated from a wind turbine

In fact, the noise will spread in all directions and if there are no reflections or reverberation, then the sound intensity decreases inversely proportional to the square of the distance from the source, that is, with $1/d^2$ from the measuring point to the sound source, so that doubling of the distance deceases the sound intensity to a quarter of its initial value.

According to the calculated results, the noise level at rotor of wind turbine exceeded the permissible limit in QCVN-26:2010/BTNMT regulation and IFC/WB standard. With the noise level at the source of 106.9 dBA, the noise was reduced to 45.03 dBA at a distance of 500m from the rotor axis of the wind turbine. Outside the range of 170-180 m from the foundation of the wind tower, the noise level generated from each turbine is considered within QCVN-26:2010/BTNMT (MoNRE., 2010). And outside the range of 500 m from the foundation of the towers, the noise level generated from the WT is considered within IFC/WB standard noise for residential area (45 dBA for night-time only).

4.2. For the cumulative noise levels at three noise sensitive areas

It is evident from Table 11 and Table 12 showed that the resonant noise levels during day-time are usually 0.4-0.5 dBA lower than that during night-time. The project site is directly affected by the oceanic climate and noise caused by sea wave interactions and atmospheric (wind) during night-time contributed to the cumulative noise intensity.

Predicted noise levels at identified noise sensitive locations during day-time are well within the Vietnamese applicable regulation and IFC standard, and therefore the impact magnitude will be small during day-time. However, during night-time there is moderate exceedance from the applicable IFC standard at three receptors and hence the impact magnitude during night time is considered as medium. Therefore, the impact significance of noise on identified receptors due to operation of WTs during day-time is considered as small, whereas during night-time, it will be medium. The significance of the impacts are identified and described in Tables 14, 15 below.

Table 14. Impact consideration during day-time

Impact	Noise generation from operation of 18 WTs				
Impact nature	Negative	Positive	Neutral		
Impact type	Direct	Indirect	Induced		
Impact duration	Temporary	Short-term	Long-term	Permanent	
Impact scale	Local	Regional	International		
Impact magnitude	Positive	Negligible	Small	Medium	Large
Impact significance	Negligible	Minor	Moderate	Major	
	Significance of impact is considered as small for all the receptors				

Table 15. Impact consideration during night-time

Impact	Noise generation from operation of 18 WTs				
Impact nature	Negative	Positive	Neutral		
Impact type	Direct	Indirect	Induced		
Impact duration	Temporary	Short-term	Long-term	Permanent	
Impact scale	Local	Regional	International		
Impact magnitude	Positive	Negligible	Small	Medium	Large
Impact significance	Negligible	Minor	Moderate	Major	
	Significance of impact is considered as moderate for all the receptors				

To mitigate noise impacts from wind turbines during the operation phase, following measures are proposed: Regular maintenance of WTs; periodic monitoring of noise near to the sources of generation to ensure compliance with design specification; and periodic monitoring of ambient noise levels (during day-time and night-time) at identified residential receptors and sensitive locations for determination of actual impact due to operation of WTs.

5. Conclusions

In this study, the authors presented the modeling method for estimating and predicting the cumulative noise levels in the Nexif Energy Ben Tre wind power plant area, and calculated results are reliable. The overview and analysis of literature sources reveal that the noise generated from WTs depends mainly on aerodynamic phenomena and the processes that generate mechanical noise, and the intensities of which are a function of wind speed. When identifying total cumulative noise levels of the project site, it is necessary to estimate background noise levels and noise levels generated from WTs as well as all wind energy facilities in the vicinity having the potential to increase noise levels.

The obtained results showed that the importance of using modeling methods in quantifying the noise levels generated by wind turbines, and for the cumulative noise levels emitted from 18 wind turbines of the Nexif Energy Ben Tre wind power plant met IFC standard and Vietnamese regulation on noise during daytime, but did not meet IFC standard on noise during nighttime. On the other hand, the level of background noise measured during night-time in the project area also does not meet IFC standard. Therefore, the overall cumulative noise level exceeds the IFC standard for residential area (45 dBA only).

Acknowledgments

We would like to express our gratitude to the Faculty of Environmental Sciences, VNU University of Science, Vietnam National University, Hanoi for their invaluable support for this research.

All data and information related to Nexif Energy Ben Tre wind power plant is retrieved and used with permissions from the leader of the project management Company for scientific purposes. We wish to extend our gratitude to the Company for this generosity.

References

Alberts D.J., 2006. Primer for Addressing Wind Turbine Noise. Research report. Lawrence Technological University, 19pp.

Colin H., Hansen K.L., B. Zajamsek, 2017. The Occurrence of Nocturnal Wind Farm Rumbling Noise. 7th International Conference on Wind Turbine Noise. Rotterdam. The Netherlands, 2nd-5th May, 123-130.

Di Napoli C., 2011. Wind turbine noise assessment in a small and quiet community in Finland. Noise Control. Eng. J., 59, 30-37.

Evans T., Cooper J., 2012. Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms. Acoustics Australia, 40, 28-36.

EVN (Vietnam Electricity Group), 2021. Status of wind power development in Vietnam 2021, 19pp.

Frey B.J., Hadden P.J., 2007. Noise radiation from wind turbines installed near homes: Effects on health. Available from: www.windnoisehealthhumanrights.com.

G. Guidati, J. Ostertag, S. Wagner, 2000. Prediction and reduction of wind turbine noise: an overview of research activities in Europe. American Institute of Aeronautics and Astronautics Paper 2000-0042.

Hansen C.H., Doolan C.J., Hansen K.L., 2017. Wind farm noise: measurement, assessment and control. John Wiley & Sons, 624pp.

ISO 9613-1, 1993. Acoustics - Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere. International Organization for Standardization, Geneva.

ISO 9613-2, 1996. Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation. International Organization for Standardization. Geneva.

ISO/TR 17534-3, 2015. Acoustics - Software for the calculation of sound outdoors - Part 3: Recommendations for quality assured implementation of ISO 9613-2 in software according to ISO 17534-1. International Organization for Standardization.

Jana Fischereit, et al., 2016. Modelling tidal influence on sea breezes with models of different complexity. Meteorologische Zeitschrift, 25(4), 343-355.

Krogh C., et al., 2021. A Self-Reporting Survey: Adverse Health effects, Industrial wind turbines, and the need for vigilance monitoring. Bull Sci. Technol. Soc., 334-345.

Leventhall G., et al., 2009. Prediction and assessment of wind turbine noise, Agreement about the relevant factors for noise assessment from wind energy projects. Acoustics Bulletin, 34, 35-37.

MoIT/GIZ Energy Support Programme, 2018. Guidelines on environmental and social impact assessment for wind power projects in Vietnam, 96pp.

Moller H., Pedersen C.S., 2011. Low-frequency noise from large wind turbines. J. Acoust. Soc. Am., 129, 3727-3744.

MoNRE (The Minister of Natural Resources and Environment), 2010. National technical regulation on noise of Vietnam (QCVN-26:2010/BTNMT).

Nguyen K.Q., 2007. Wind energy in Vietnam: Resource assessment, development status and future implications. Energy. Policy., 35, 1405-1413.

Nguyen Thi Tuyet, Ngo Duc Thanh, Phan Van Tan, 2019. Performance of SEACLID/CORDEX-SEA multi-model experiments in simulating temperature and rainfall in Vietnam. Vietnam J. Earth Sci., 41(4), 374-387.

Nissenbaum M.A., et al., 2012. Effects of industrial wind turbine noise on sleep and health. Noise & Health, 14, 237-243.

Ofelia Jianu., Marc A. Rosen., Greg Naterer., 2011. Noise Pollution Prevention in Wind Turbines: Status and Recent Advances, 14pp.

PECC5 (Power Engineering Consulting Joint Stock Company 5), 2019. Feasibility study report of Nexif Energy Ben Tre wind power plant project, 158pp.

Pham Thi Ly, Hoang Luu Thu Thuy, 2019. Spatial distribution of hot days in north central region, Vietnam in the period of 1980-2013. Vietnam J. Earth Sci., 41(1), 36-45.

Pierpont N., 2009. Wind Turbine Syndrome: A Report on a Natural Experiment. Santa Fe, (NM): K Selected Publications.

Rogers A.L., Manwell J.F., Wright S., 2006. Wind Turbine Acoustic Noise. Renewable Energy Research Laboratory, Department of Mechanical and Industrial Engineering University of Massachusetts at Amherst. Amended.

S. Oerlemans, P. Sijtsma, 2008. Location and quantification of noise sources on a wind turbine. Nationaal Lucht - en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR. Netherlands, 38pp.

S. Wagner, R. Bareiss, G. Guidati, 1996. Wind Turbine Noise. Springer Verlag.

SESTEV (School of Environmental Science and Technology and ERM Vietnam), 2019. Report of existing noise levels in Thanh Hai and Thanh Phong

Communes, Thanh Phu District, Ben Tre Province, Vietnam, 80pp.

Tickell C.E., J.T. Ellis., M. Bastasch, 2004. Wind turbine generator noise prediction - Comparison of computer models. Proceedings of Acoustics. Gold Coast. Australia, 3-5 November 2004, 45-50.

Tran Trong Hung, Tran Anh Tu, Dang Thuong Huyen, Marc Desmet, 2019. Presence of trace elements in sediment of Can Gio mangrove forest, Ho Chi Minh city, Vietnam. Vietnam J. Earth Sci., 41(1), 21-35.

VG (Vietnam Government), 2015. Decision No. 2068/QD-TTg dated 25 November 2015 on the approval of renewable energy development strategy of Vietnam up to 2030 with vision to 2050, 15pp.

VG (Vietnam Government), 2016. Decision No. 428/QD-TTg dated 18 March 2016 of the Prime Minister, the approval of revisions to the national power development plan from 2011 to 2020 with visions extended to 2030, 14pp.

WHO (World Health Organisation), 2009. Night noise guidelines for Europe. Copenhagen.

WWA (World Wind Atlas), 2019. Available: https://globalwindatlas.info/ (accessed on September 23, 2019).