REPORT

Wind Energy Development Prospectus: 120 MW Project in Aceh Besar, Aceh

2024

This document is produced as part of the Southeast Asia Energy Transition Partnership's 'Wind Energy Development in Indonesia: Investment Plan' Project

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1 Introduction of the Wind Farm Prospectus

This wind farm prospectus is one of the deliverables under the project titled *Wind Energy Development in Indonesia: Investment Plan*. The project is initiated by the Ministry of Energy and Mineral Resources of the Republic of Indonesia (MEMR), managed by the Southeast Asia Energy Transition Partnership (ETP), and hosted by the United Nations Office for Project Services (UNOPS). ETP is a multi-donor partnership formed by governmental and philanthropic partners to accelerate sustainable energy transition in Southeast Asia in line with the Paris Agreement and Sustainable Development Goals. UNOPS is the fund manager and host of ETP Secretariat.

Eight potential wind farm locations on Java and Sumatra have been assessed on their techno-economic viability. These locations are Aceh Besar (Aceh), Dairi (North Sumatra), Gunung Kidul (DI Yogyakarta), Kediri (East Java), North Padang Lawas – South Tapanuli (North Sumatra), Ponorogo (East Java), Probolinggo – Lumajang (East Java), and Ciracap (West Java). Findings from the study are consolidated in a wind farm prospectus per location, of which the underlying document is created for the Aceh Besar wind farm. In each prospectus, the following items are included:

Section 2.1: Introduction of the location

- Geographic location
- The mentioning in PLN Electricity Supply Business Plan (*Rencana Umum Penyediaan Tenaga Listrik*/RUPTL) 2021-2030 and current development status

Section 2.2: Wind resource availability and land use

- Wind characteristics at the envisioned area
- Topography at the envisioned area
- Land use at the envisioned area, including permitting requirements
- Conclusion on the boundaries of the envisioned wind farm area

Section 2.3: Design of the preliminary wind farm layout

Section 2.4: Accessibility

- Transportation to the wind farm, including necessary road adjustments and construction of new infrastructure
- Transportation within the site, including necessary road adjustments and construction of new infrastructure

Section 2.5: Geology and seismicity conditions

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Section 2.7: Transmission network design

- Selection of the point of connection at the PLN grid
- Schematic design of transmission and distribution network

Section 2.8: Energy yield assessment, based on the wind resource availability and preliminary wind farm layout

Section 2.9: Business case assessment, based on the wind farm cost and energy yield

Section 3: Overall conclusion on the techno-economic viability of the wind farm and recommended next steps in the development of the wind farm

2 Analysis of Aceh Besar Wind Farm, Aceh – 120 MW

2.1 Introduction of the wind farm location

This section introduces the wind farm location, i.e. Aceh Besar, Aceh in three parts: (1) geographic location, (2) status in RUPTL, and (3) status of development.

2.1.1 Geographic location

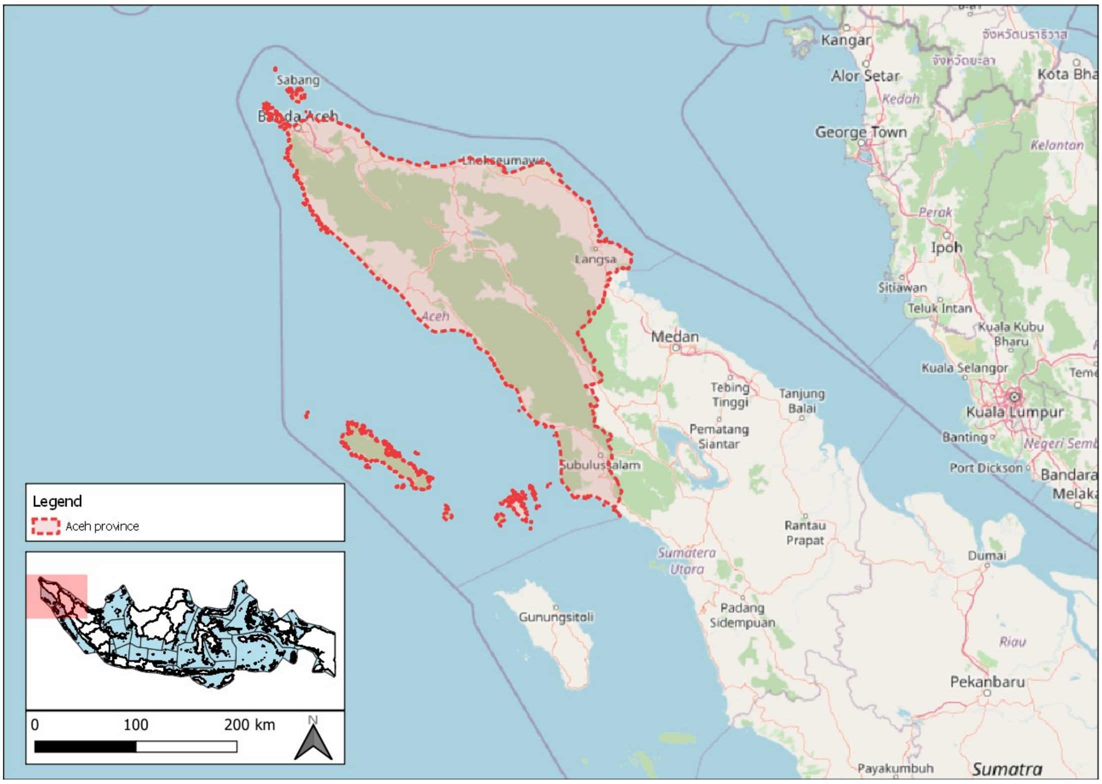

Figure 1. A map of Aceh province in which the envisioned Aceh Besar wind farm area is located.

Figure 1 shows Aceh, a province at the northwestern tip of Sumatra Island. Located in the western part of Indonesia, Aceh is a neighbor to one province: North Sumatra. Aceh has an area of 58,486 km^2 and a population of roughly 5.4 million in 2022[1]. This province is ranked 30^{th} in terms of provincial GDP per capita, which amounts to IDR 39.16 million[2]. Additionally, the cumulative economic growth of Aceh in 2023 is 4.23% (c-to-c)[3]. To provide context, Indonesia's economic growth in that year is 5.05% (c-to-c)[4].

[1] https://aceh.bps.go.id/indicator/12/55/1/jumlah-penduduk.html
[2] https://www.statista.com/statistics/1423411/indonesia-per-capita-gdp-at-current-prices-of-provinces/
[3] https://aceh.bps.go.id/pressrelease/2024/02/05/1085/pertumbuhan-ekonomi-triwulan-iv-2023-provinsi-aceh.html
[4] https://www.bps.go.id/en/pressrelease/2024/02/05/2379/indonesias-gdp-growth-rate-in-q4-2023-was-5-04-percent--y-on-y-.html

There are a number of things to note about Aceh. The province was granted special autonomy for historical reasons, one of them being the only province in Indonesia that implements the Sharia law. Aceh is also known for having sizable oil and gas reserves. Two recent 'giant' offshore discoveries announced in early 2024 is at Andaman II and South Andaman Block, which respectively estimated to contain 5.5 and 6 trillion cubic feet (TCF) of gas-in-place[5]. Aceh is home to a 1 million-ha large nature reserve, named Mount Leuser National Park. Moreover, some key agricultural products of Aceh include palm oil, coffee, cacao, rubber, and rice.

There is one industrial estate in Aceh[6], namely, Aceh Ladong Industrial Estate (66 ha [7]). This estate is envisioned to become one of Indonesia's National Halal Industrial Estate that supplies halal food and beverages to the Middle East [7,8]. Meanwhile, there is one special economic zone (SEZ) in the province: Arun Lhokseumawe SEZ (2,622 ha)[6]. Inaugurated in 2018, this SEZ is developed to focus on several sectors including energy (gas), petrochemical, agroindustry, logistics, and kraft paper[9].

In Appendix E of RUPTL PLN 2021-2030, PLN lists the strategy to fulfill new/additional power demand from four 'large' electricity consumers in Aceh, namely:

1. Arun Lhokseumawe SEZ (10 MVA in 2025; potential for further development of 350 MW)
2. Ladong Industrial Zone (10 MVA in 2025)
3. Sabang Integrated Marine Fisheries Center (0.2 MVA in 2025)
4. East Aceh Shrimp Pond (2 MVA in 2025)

The next subsection will explain the projected power demand levels of the province, which among others considers the future demand from the abovementioned consumers.

The considered wind farm location in Aceh is located in the Aceh Besar Regency, in the southwest of provincial capital city Banda Aceh.

2.1.2 Status in RUPTL PLN 2021-2030

The electricity system of Aceh is presented in Figure 2. This system is comprised of a backbone 150-kV transmission line connected to the Northern Sumatra (*Sumbagut*) interconnection, and an isolated system using a 20-kV transmission line. The former line connects a majority of the Aceh onshore regions (main island), whereas the latter serves electricity provision mainly at the smaller islands. RUPTL PLN 2021-2030 states that the peak load in Aceh in 2020 is recorded at 542 MW.

The projected peak load, as well as the projected electricity production at the province, is displayed in Figure 3. It can be inferred from the figure that PLN expects electricity demand to have a stable growth until 2030. This projection is based on the assumption that the average demand growth rate will be 4.7% per year.

[5] https://www.cnbcindonesia.com/news/20240115175421-4-506054/bukan-mitos-segini-jumlah-temuan-gas-raksasa-di-aceh
[6] https://regionalinvestment.bkpm.go.id/pir/kawasan-industri-kek/
[7] https://investaceh.id/projects/detail/kawasan-industri-aceh-kia-ladong
[8] https://kemenperin.go.id/artikel/22941/Kemenperin-Dorong-Masuknya-Investor-ke-Kawasan-Industri-Ladong
[9] https://regionalinvestment.bkpm.go.id/pir/kawasan-industri/?id=85

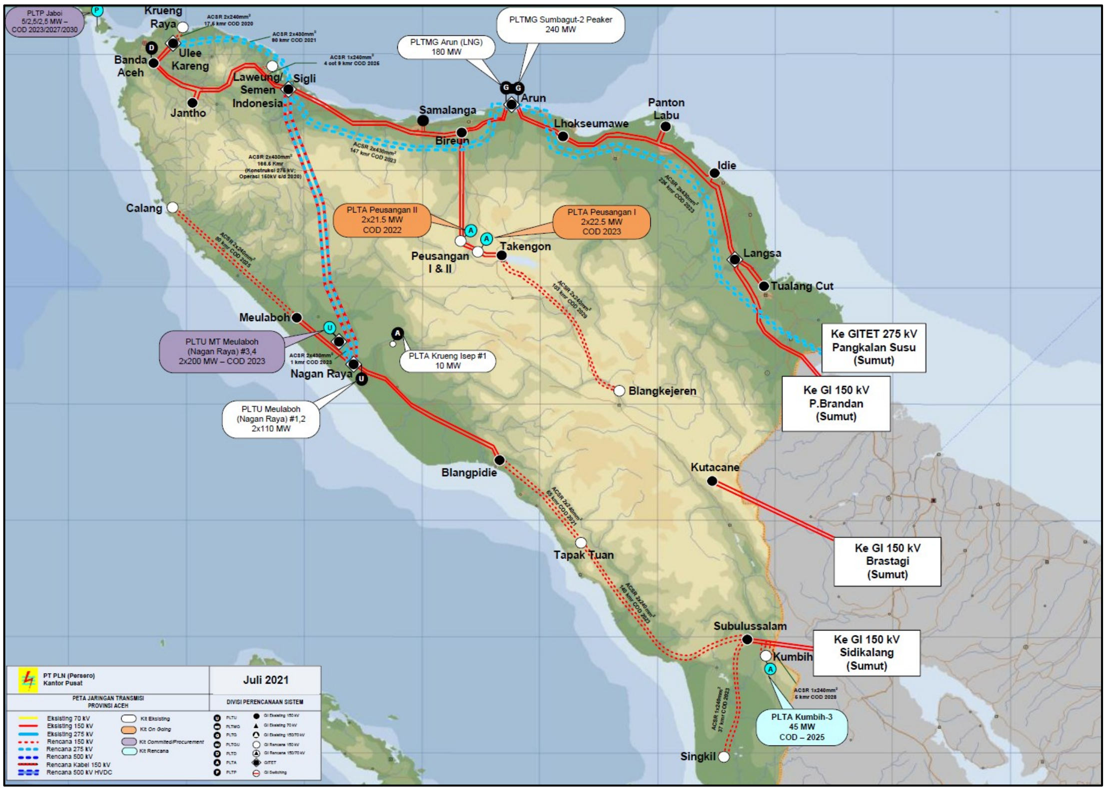

Figure 2. A map of Aceh electricity system in RUPTL (Source: RUPTL PLN 2021-2030).

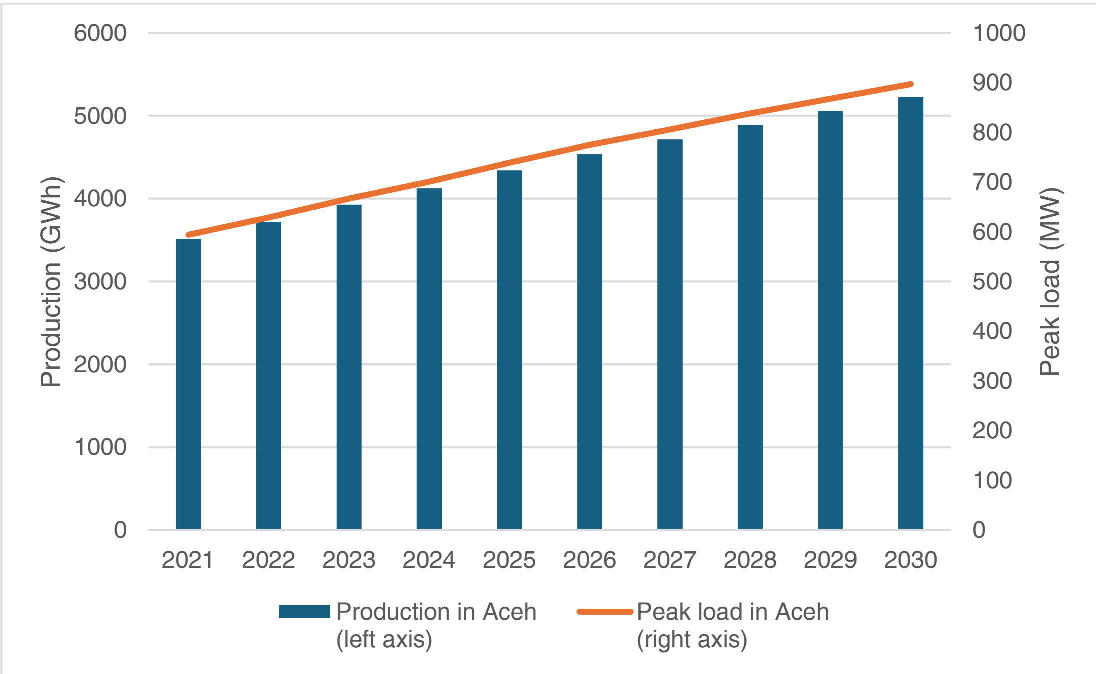

Figure 3. Projected electricity production and peak load in Aceh (Source: RUPTL PLN 2021-2030).

A summary of the power generation development planning can be seen in Figure 4. This figure includes both conventional and renewable energy power plants. Additional power generation is categorized into two groups: PLN and Independent Power Producer (IPP). Throughout 2021-2030, wind energy development is allocated 55 MW each for 2024 and 2025, totaling 110 MW. It is noteworthy that the allocation is applicable for the whole Sumatra system (including other provinces). On top of this allocation, the RUPTL also identifies 148 MW of wind power potential in Aceh.

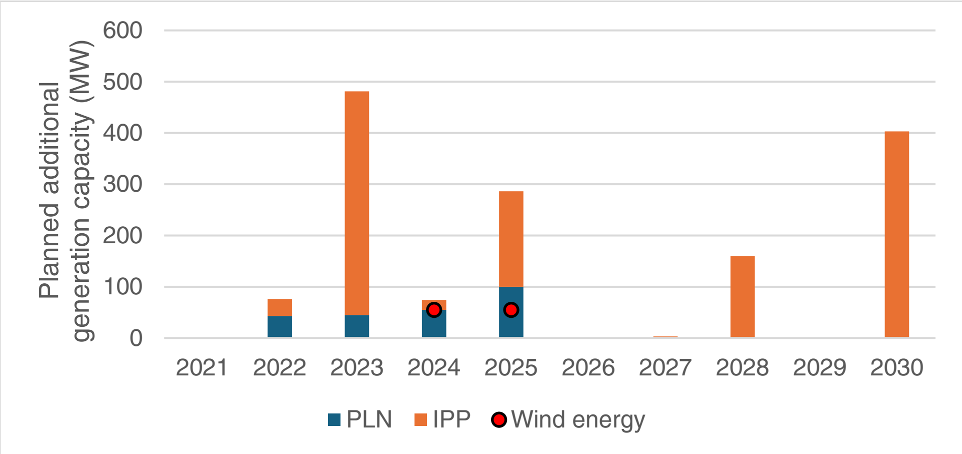

Figure 4. Additional generation capacity being planned for Aceh (IPP: Independent Power Producer; Source: RUPTL PLN 2021-2030).

2.1.3 Status of development

Aceh wind farm (PLTB Aceh; 55 MW) was included in the Hijaunesia 2023 tender conducted by PLN. To the best of our knowledge, there are at least two developers active in Aceh and participated in the tender. However, the tender winner has not yet been announced up to the time of writing. This project has since been included as one of the JETP Comprehensive Investment and Policy Plan (CIPP) top priority wind projects, with COD target of 2027 and capacity of 55 MW. It can be concluded that there is still room for further wind energy development considering the potential and the power generation planning.

2.2 Wind resource availability and land use

2.2.1 Approach

To determine the area in which wind turbines can be placed, one of the most important factors to consider is wind speed. This factor largely determines the envisioned boundaries of the area suitable for the construction of wind turbine generators (i.e. WTG-area). In the later process, additional factors were taken into consideration, which led to a final WTG-area. This section provides a concise overview of the factors that have resulted in the final WTG-area. The data used to shape the WTG-areas was based on open-source geo-information. Additional field checks have shown that the open-source data provides a sufficient level of detail in this phase of the project.

The WTG-area selection for this location starts with identifying areas with average wind speeds above 6 m/s at 100 m height. This initial filtering process using wind speed data is followed by the inclusion of further parameters, including land use (roads, railways, residential areas and buildings) and topography (slopes). Additionally, the volcanic and seismic risks are later taken into consideration in Section 2.5. To summarize, the first set of restriction criteria being applied in the WTG-area selection are as follows:

- Wind speed (> 6 m/s)
- Slopes (< 15 degrees, with a buffer of 100 m around steep ridges)
- Roads (with a buffer of 150 m)
- Railways (with a buffer of 150 m)
- Residential areas and buildings (with a buffer of 250 m)

The next step was to consider the "go/no-go zones." As the name suggests, these zonal categories indicate whether a particular area either can accommodate wind farm developments without significant restrictions/conditions to be fulfilled (go zone), can accommodate wind farm developments with significant restrictions/conditions to be fulfilled (go zone with restrictions), or cannot accommodate wind farm developments (no go zone). These zones were determined considering the land use, i.e. presence of nature reserves, protected areas, and airports, as well as water ways and water bodies, based on OpenStreetMap (OSM). Furthermore, existing policies (e.g. spatial plans) and regulations (e.g. on permitting) specific to the area are also considered.

A specific buffer distance was applied to each case to minimize the risk of possible nuisance, safety issues, and land use conflicts. This step results in the final WTG-areas. The second set of restriction criteria that were checked thus include:

- Nature reserves and protected areas (with a buffer of 300 m)
- Airports (with a buffer of 3,000 m)
- Water ways and water bodies (with a buffer of 300 m)

2.2.2 Wind resource and characteristics

Figure 5 shows the initial search area (bounded by the purple-dash box), in the northwestern region of Aceh. Within the figure, areas with average wind speeds of more than 6 m/s are indicated by the "pixels" with distinct color as described by the color bar. It can be concluded that promising wind resources are located in elevated parts of the area.

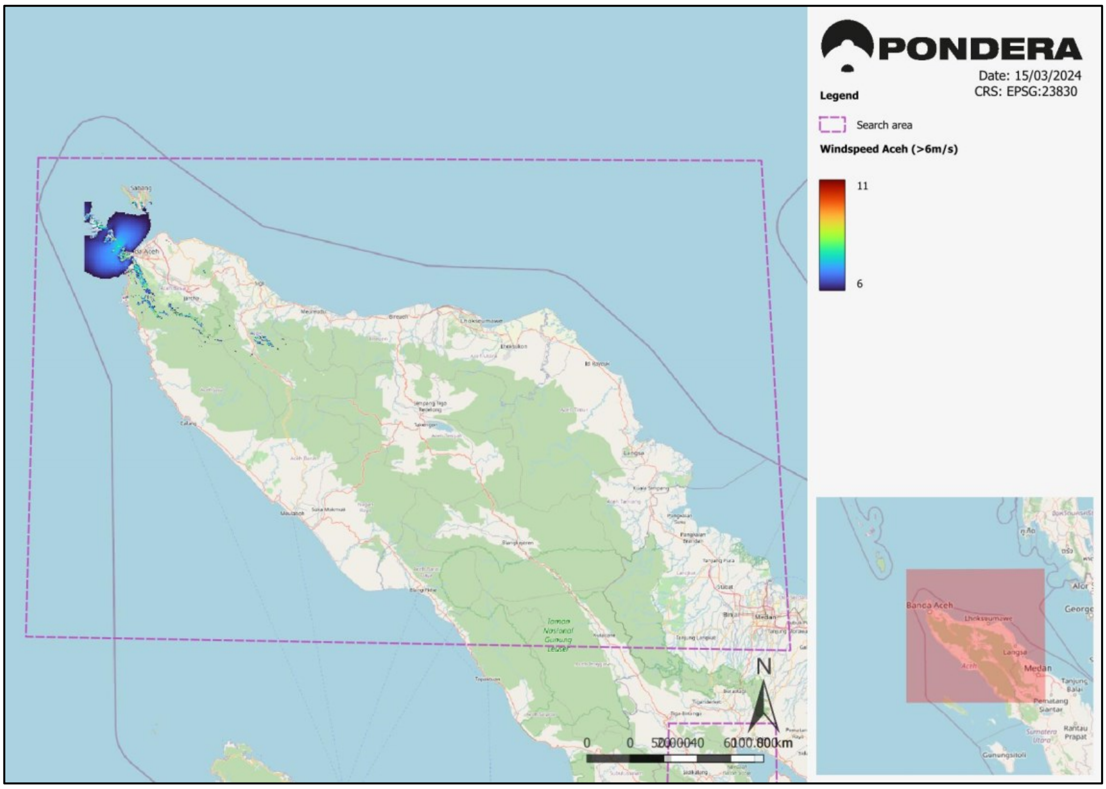

Figure 5. Aceh search area with wind speed distribution. The purple-dash bounding box shows the full search area. The color bar indicates average wind speeds which are above 6 m/s at 100 m height according to the Global Wind Atlas (GWA) climatology.

Considering the scattered nature of the areas with promising wind speed, the search area was further confined to a single smaller, continuous area to safeguard the project's viability. The reason behind this is to avoid the high cost and complexity of building electrical connections (e.g. distribution lines) between the several sub-sites of wind turbines which are separated by large distances.

Figure 6 shows a zoomed-in map of this continuous area which has been further studied in the subsequent steps. The figure is also complemented by the final WTG-area to give an idea of the level of wind speed at the location.

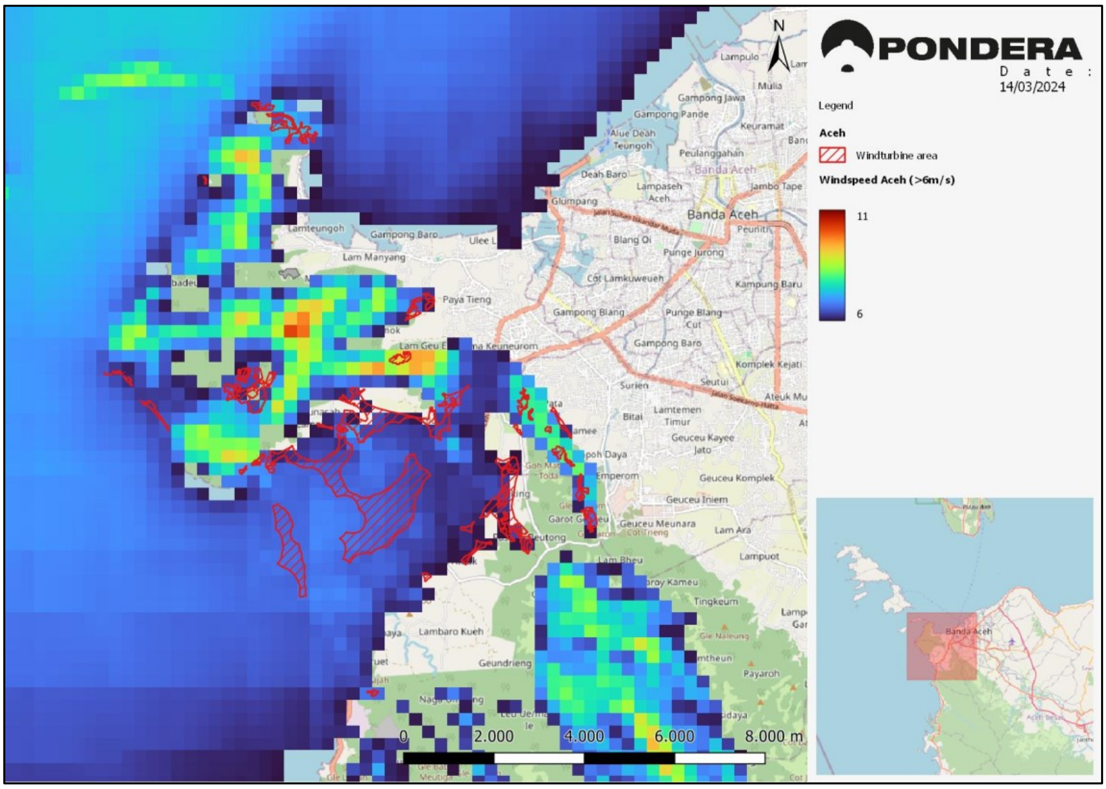

Figure 6. A zoomed-in look at the Aceh search area, along with the wind speed distribution. The red, dashed polygons represent the final WTG-area which meets all the criteria. Average wind speeds above the threshold of 6 m/s at 100 m height according to GWA are shown.

Additionally, Figure 7 visualizes the long-term average wind direction distribution for the Aceh Besar area. As can be interpreted from this figure, the wind climate in the area primarily consists of wind from the Southwestern direction.

In Figure 8, the wind speed distribution throughout the day for each month per year is visualized. The highest wind speeds are observed between May and October, when the intertropical convection zone (ITCZ), is positioned north of the site. Therefore, this period can also be distinguished from the other months by the prevailing southwestern wind directions. Approximately from November until April (though the timing can vary from year to year), when the ITCZ is passing over the site towards the south, the lowest wind speeds are observed. As expected, during these months most of the eastern are observed.

Besides the annual wind speed and direction patterns, which strongly depend on the positioning of the ITCZ, interannual variations are caused by the El Niño and La Niña phenomena. During a strong El Niño year, the trade winds are weaker, while during a La Niña year, they are strengthened, resulting in higher wind speeds over the area.

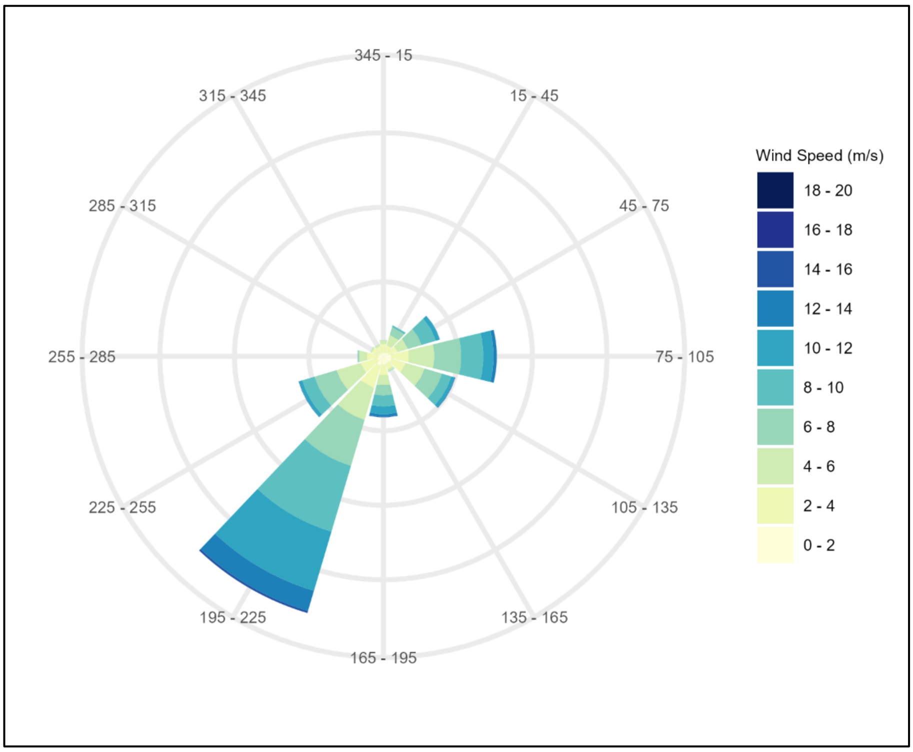

Figure 7. Wind rose diagram with wind directions and wind speed categories based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

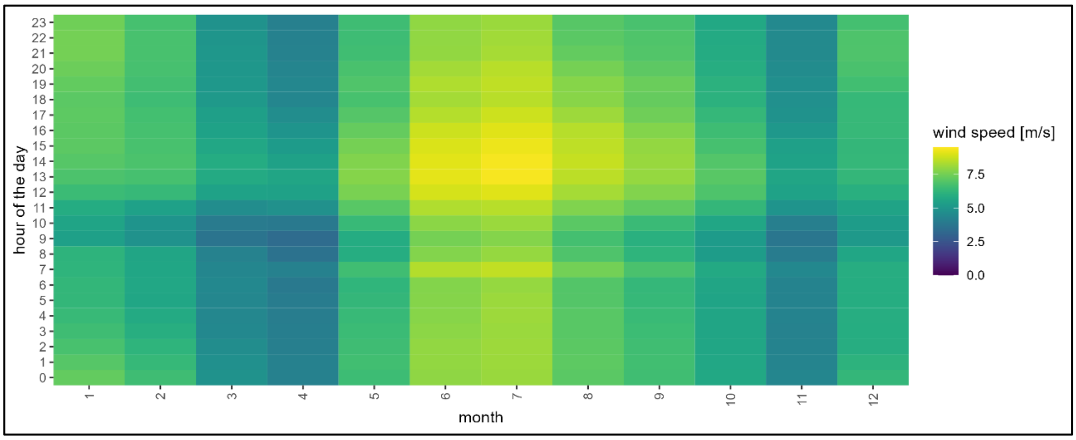

Figure 8. The wind speed distribution throughout the day, visualized per month of the year. Based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

2.2.3 Topography

Figure 9 shows the topography of the search area in the Aceh Besar region. The red, dashed polygons represent the final WTG-area which meets all the criteria. The steepness of the terrain or slope is expressed in degrees. The slope calculations are based on the FABDEM elevation grid which has a resolution of approximately 30 m. In this study, areas with slopes higher than 15 degrees are excluded from further analysis to avoid excessive cost of transportation and construction commonly entailed with wind farm projects at steep terrains. Nevertheless, it is noteworthy that due to the data resolution, this exclusion criterion does not consider small scale (i.e. less than 30 m) fluctuations in elevation.

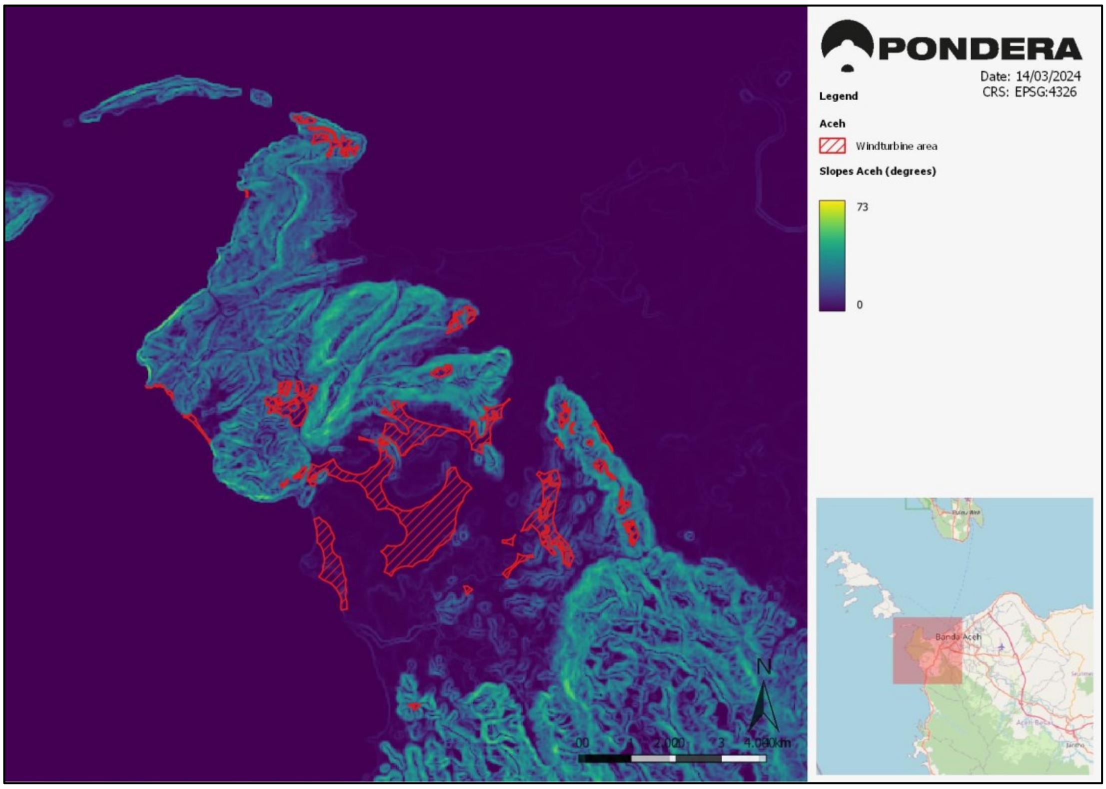

Figure 9. Topography of the Aceh Besar WTG-area, showing the slope (in degrees; according to calculated based on FABDEM data) at the region.

2.2.4 Land use

As mentioned in the previous subsections, wind farms cannot be realized in areas too close to buildings, infrastructure, nature reserves, and water bodies. Therefore, buffers are applied to these objects to determine suitable WTG areas. Aggregating the aforementioned restriction criteria give the land use exclusion zones (see Figure 10). These exclusion zones were taken out of consideration in the next stages of this study. Consequently, this analysis produces the final WTG-area as marked with the red, dashed polygon in Figure 10.

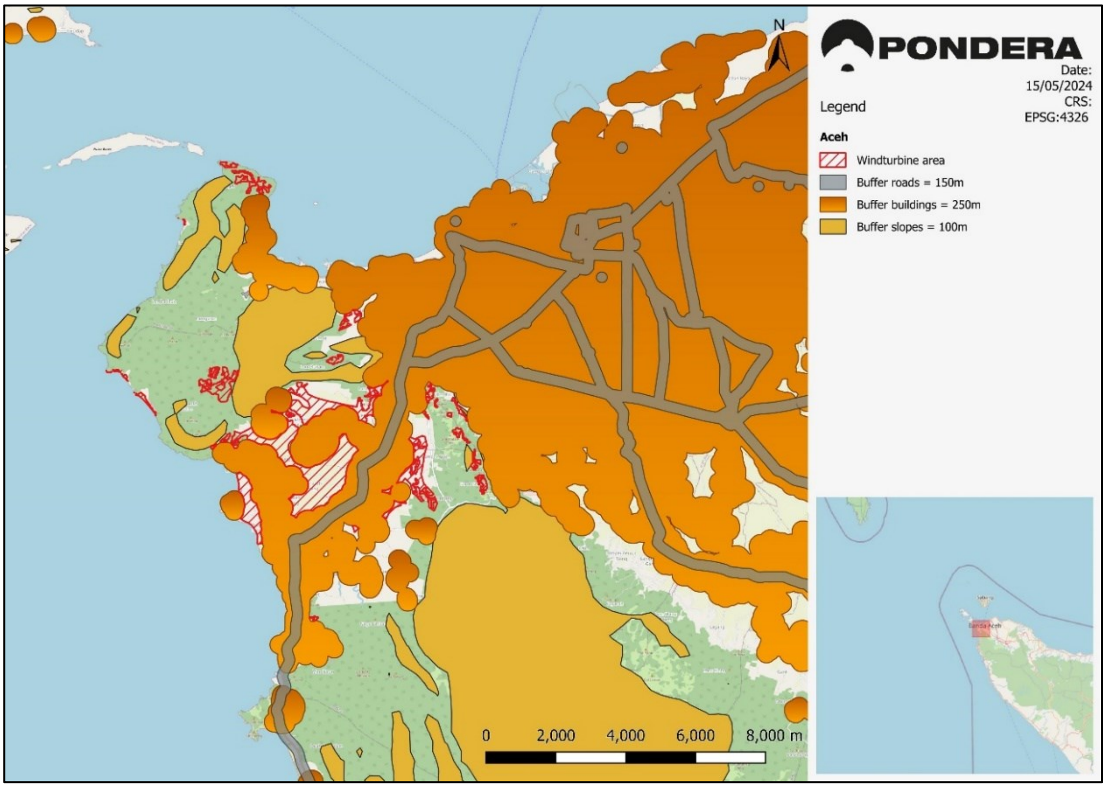

Figure 10. Exclusion zones at the Aceh Besar area based on land use, topography, and residential areas. Source: calculation based on FABDEM elevation, ESRI, and OSM.

2.2.5 Specific permitting requirements

The spatial plan document being referred to in this analysis is the Aceh Besar Regency Spatial Plan (RTRW) 2013-2033. Although there is a plan to revise the spatial plan, the current version is still valid at the time of writing. Figure 11 sets the final WTG-area against the spatial plan map. Based on the figure, it can be inferred that the final WTG-area overlaps with the following spatial plan categories:

1. Plantation Area (*Kawasan Perkebunan*)
2. Dryland Farming/Agricultural Area (*Kawasan Peruntukan Pertanian Lahan Kering*)
3. Wetland Farming/Agricultural Area (*Kawasan Peruntukan Pertanian Lahan Basah*)
4. Mining Area (*Kawasan Pertambangan*)
5. Urban Settlement Area (*Kawasan Pemukiman Pedesaan*)
6. Protected Forest Area (*Kawasan Hutan Lindung*)
7. Coastal Border Area (*Kawasan Sempadan Pantai*)
8. Horticulture Area (*Kawasan Hortikultura*)

Of the eight categories above, the final WTG-area mostly overlaps with the first three categories above. Meanwhile, the overlap with the remaining five categories is relatively minor, and thus, it is excluded from further analysis in this study.

Parts of the final WTG-area which are within the Plantation Area can be used for public-interest development, including wind farm development (and other types of power generation and transmission activities) if a mutual agreement can be reached with the landowner[10]. The landowner could be assumed to either be (state-owned or private) companies or the local community. In the former case, a formal agreement with the owner of Plantation Business Use Rights (*Hak Guna Usaha Perkebunan*) is expected to be needed before wind farm development can take place. Meanwhile, the latter case could involve a purchase or lease agreement with the landowner. Similarly, the final WTG-area in Dryland Farming/Agricultural Area and Wetland Farming/Agricultural Area can be used for wind farm development if a purchase or lease agreement is obtained[10].

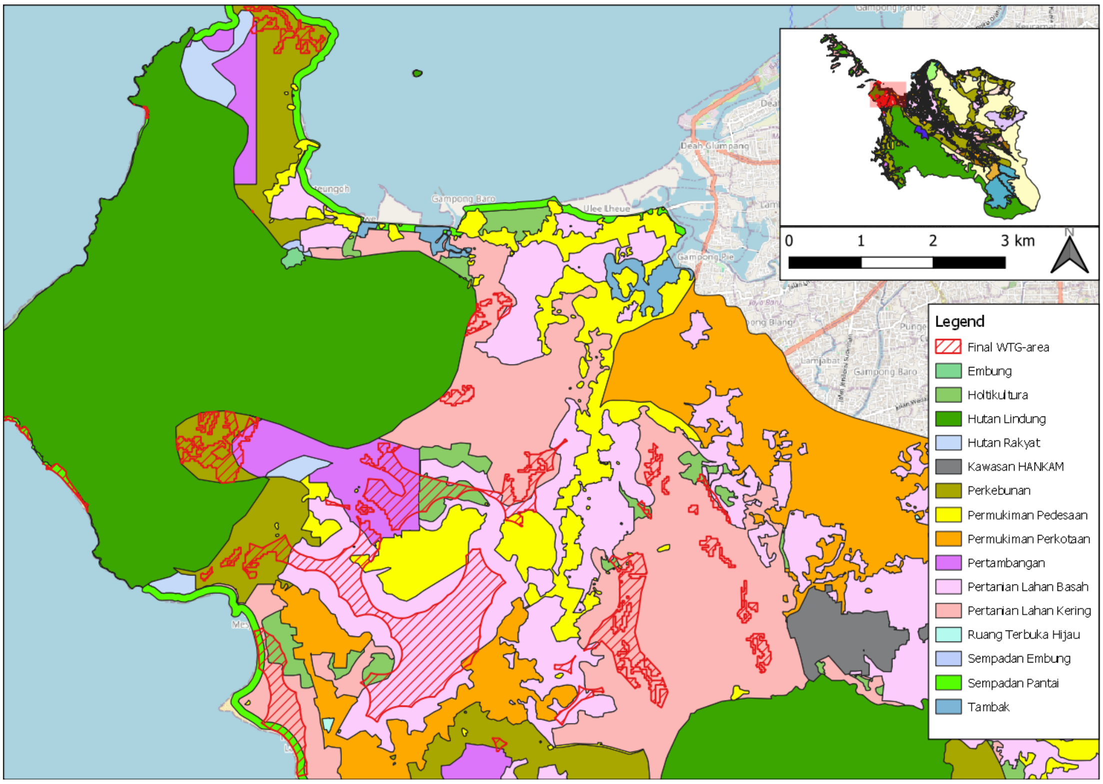

Figure 11. The map of spatial plan of Aceh Besar Regency (RTRW 2013-2033) overlaid with the final WTG-area in the regency

[10] Referring to Law 22/2019, Presidential Regulation 59/2019, and Government Regulation 1/2011.

2.2.6 Final WTG-area

An overview of the final WTG-area against the satellite image at the location can be found in Figure 12. This area meets all the criteria as visualized in the previous figures.

Limitations

As mentioned before, the parameters that have shaped the final WTG-area have been based on open-source geo-information. A site visit to some portions of the area was conducted to obtain a deeper understanding of the area's characteristics (as explained further in Section 2.4 to Section 2.6), from which general conclusions are then drawn to further analyze the final WTG-area.
The site visit has shown that in general:

1. The residential areas data derived from the ESRI-database underestimates the buildings in the region, and therefore, in some cases this might necessitate additional exclusion zones in a later stage of the project;
2. In some cases, the water ways were too restrictive (considering the size of the streams), and thus, they were left out of the analysis (i.e. those waterways were not considered as a restriction); and
3. The primary roads data derived from OSM also include small roads; consequently, this dataset might be too restrictive in some cases.

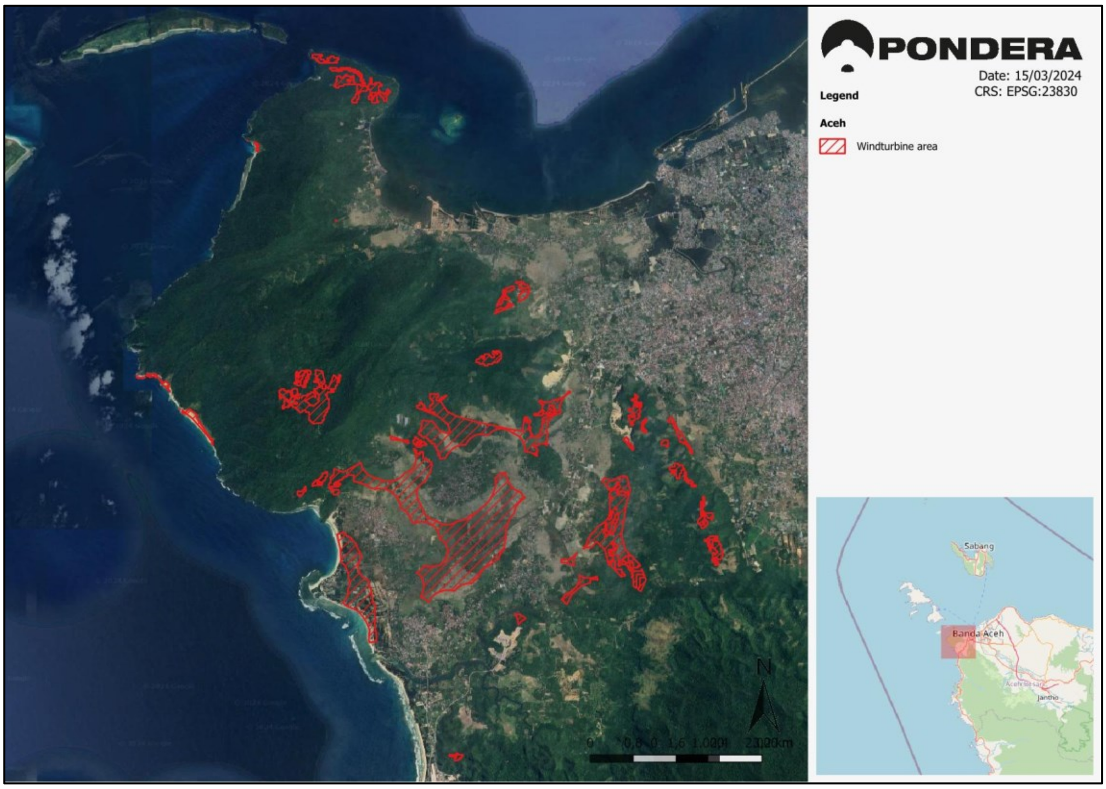

Figure 12. Final WTG-area based on the restriction criteria. Source: Google Satellite Images.

2.3 Preliminary wind farm layout

The wind farm layout is based on the WTG-areas provided in Section 2.2. The preliminary wind farm layout is designed based on bundling of as many wind turbine positions as possible. This prevents for example constructing a road and cables to a single wind turbine location, which is not cost effective.

As the Indonesian wind climate generally consists of areas with lower to medium wind speeds, a wind turbine type that suits these wind conditions should be selected. For a provisional wind farm layout, a 4 MW reference wind turbine with a rotor diameter of almost 170 m and a hub height of 140 m has been used. This makes the total tip height around 220-225 m. To reduce the wake losses and possible negative turbulence influences, a standard distance of five times the rotor diameter was used in the preliminary wind farm layout.

During the positioning of the turbines, additional visual checks were performed based on satellite images, taking into account: 1) power lines, 2) buildings, 3) size of the area, with a minimum of three turbines in proximity, 4) accessibility of the area relative to other parts of the WTG-area, 5) minimization of the restriction criteria, 6) selection of the highest wind speed areas and 7) fulfillment of the installed capacity goals as stipulated in RUPTL PLN 2021-2030.

Figure 13 displays an overview of the wind turbine locations in the final WTG-area. A total of 30 wind turbines were positioned into the area, amounting to an envisioned total installed capacity of 120 MW (based on 4 MW wind turbines). The red marker (red dots with black centers) indicates the exact location of the individual wind turbines, whereas the blue radial line guarantees a spacing of at least 5 times the rotor diameter.

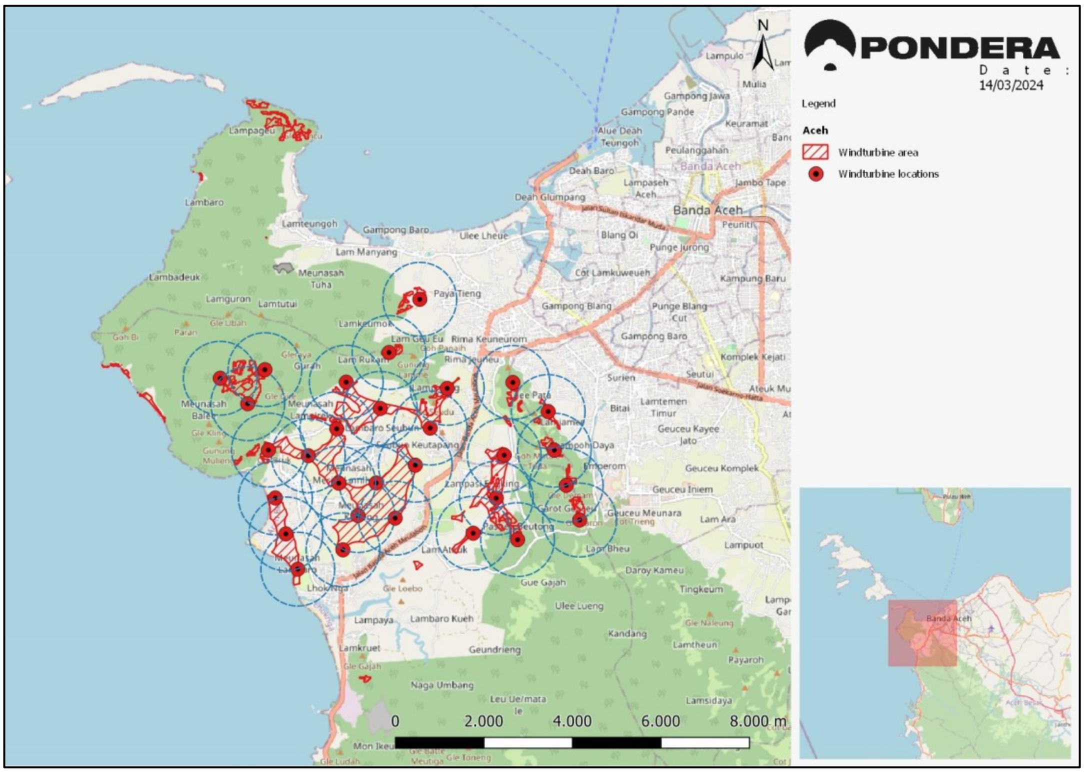

Figure 13. Preliminary wind farm layout at the final WTG-area.

2.4 Wind farm accessibility

In this section, accessibility of the wind farm is explained through three subsections: (1) the Indonesian transportation setting, (2) port-to-site transportation, and (3) transportation within the site.

2.4.1 The Indonesian transportation setting

Outside of the larger cities, regional road systems are used for almost all transportation (see Figure 14). These roads lead through the center of cities, towns, and villages they are serving. Ring roads around cities are reserved for a few major cities such as Jakarta, Bandung, Medan, Yogyakarta, and Surabaya. In a lot of cases, only one major regional road is available to go from one city to another city. This results in a situation where all traffic is using the same road, i.e. pedestrians (including groups of school children, farmers etc.), motorbikes, cars, ambulances, public transport, smaller local trucks, and large trucks for long distance transportation. While some sections of highways are available on Sumatra and more are planned or under construction, so far only Java has a continuous highway connecting the western to the eastern part of the island. This highway is situated on the northern side of Java which is more densely populated and has flatter terrain.

Usually, general utilities such as electricity distribution lines and telecommunication lines follow the same pathway as the local roads. Overhead cables right next to the road are the standard way of practice throughout Indonesia. The major powerlines and telecommunication cables are situated on one side of the road while serving both sides. This means that for all houses or groups of houses on the other side of the road, all cables have to cross the road, generally at a height of about 5 meters above the road surface. In towns and cities, these overhead crossings are typically present every 20 to 50 meters.

Figure 14. Typical road layout in rural Indonesia. Winding roads of ~6 to 7 m wide serving both local, regional, and national traffic. Overhead power- and telecommunication cables with poles on both sides of the road. Buildings are in close proximity. Within cities and larger towns, the roads are generally slightly wider, but with more overhead cables, poles, and advertisement billboards.

Urban drainage systems are normally buried underground on both sides of the road and are not suitable for the carriage of heavy transport. Buildings are in most cases present within two to five meters from the road, often 1 to 3 stories high.

This together means that space on and around Indonesian roads is very limited. Aside from the spatial challenges, there are also significant challenges arising from the duration of the transport. The transport of wind turbine components is a lengthy process. One turbine is transported in individual components (e.g. tower segments, wind turbine blades) on roughly ten trucks, excluding the building material for the foundation. Long term closure of roads may have a significant impact on the functioning of a town as alternative routes are often not available.

Transporting the blades of the wind turbines with a length of 80+ meters may be one of the most critical aspects of wind farm development in Indonesia and must be thoroughly prepared.

2.4.2 Port-to-site transportation

The nearest deep-water port of the envisioned wind farm is located in Malahayati (container port) at a distance of 45 km from the site. This is a major container port with quay cranes serving north-western Sumatra (Figure 15). There are some smaller ports available closer to the site, but they are not available to the project as they are designated as ferry port or fishing port. The water depths and space in these ports is also limited. The operator of the cement south of the project area is not willing to allow offloading of turbine blades in this port.

Figure 15. Container port of Malahayati.

Malahayati Port has served cargo ships with dimensions of 30,000 DWT. On paper, Malahayati can serve ships weighing up to 50,000 DWT or close to the Panamax class of cargo ships. The Malahayati Port contains three different quays with the following dimensions. The port has 2.5 ha storage area for turbine blades and other parts.

Table 1. Dimensions of Malahayati Port.

Malahayati Port dimensions	Quay 1	Quay 2	Quay 3	Total
Length [m]	140	100	140	380
Width [m]	16	16	26	16
Draught [m]	8-8.5 LWS	8-8.5 LWS	6-8 LWS	6-8 LWS
Total area [m^2]	2,240	1,600	3,640	6,080
Available area [m^2]	2,800	2,000	4,550	7,600

The access road from the port to the site is flat (elevations ranges between +5 m and +10 m above sea level), but roads are steep within the project site.

Figure 16. Route from Malahayati Port to the access point of the site.

The access route from port to site has a total of fourteen smaller and larger bridges. In a previous project, attempts were made to structurally evaluate these bridges. However, data on the loading capacity is not available for most bridges. While newer bridges (constructed with international support after the Tsunami) may have sufficient strength to hold heavy transports, this may not be the case with older bridges.

Figure 17. Bridge near Malahayati Port.

Figure 18. Krueng Cut Bridge in Banda Aceh.

Figure 19. National road in Banda Aceh Besar close to the project site. Wide, gentle curved roads of ~6 to 7 m wide serving both local, regional and national traffic. Overhead power- and telecommunication cables with poles on both sides of the road.

Most of the road to the project site will not pose major obstacles for transports. Even the road through Banda Aceh contains only a few tight turns (see below) and crossings.

Figure 20. Tight turn in Banda Aceh.

2.4.3 Transport within the site

While the transport via the main roads may not present many problems, the internal access roads run through small villages with narrow streets, tight turns and overhanging electricity and telephone wires, as shown in the images below.

Figure 21. Residential road in project site.

Figure 22. Another view of a residential road in project site.

Not all turbine sites can be reached via existing roads. Some roads require upgrading and new roads must be constructed. It is estimated that the following upgrade and construction is required:

- Construction of mountainous roads: 11.34 km
- Construction of flat/undulating roads: 11.95 km
- Upgrade flat/undulating roads: 10.91 km

Figure 23 shows the roads as mentioned above.

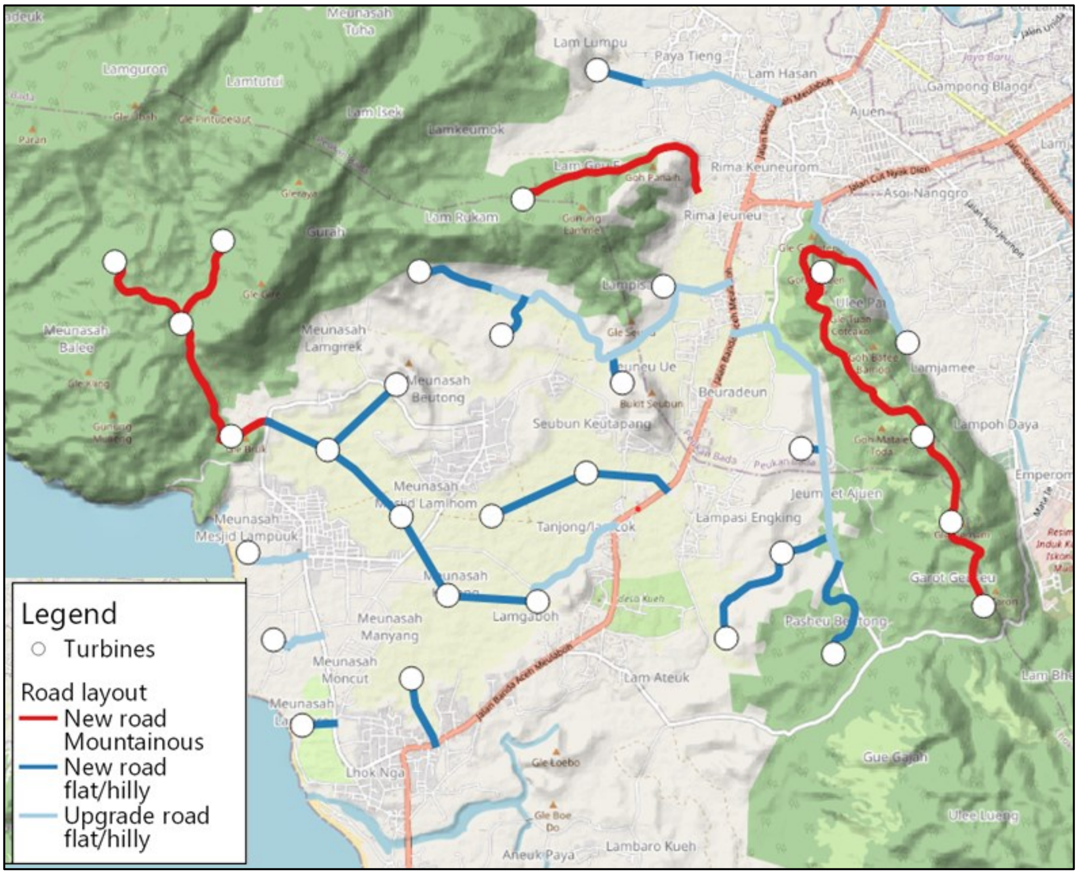

Figure 23. Internal access roads in project site.

Construction of new mountain roads in the project site will require substantial effort as the hills are poorly accessible and mountains are high with steep slopes. From a terrain perspective, the topography within the wind farm is suitable for wind farm development as the majority of roads and platforms can be built on flat terrain. However, eight turbine locations are on top of 200-250 meters high mountains with few (unpaved) roads and steep slopes.

Figure 24. Topography in the project site.

Figure 25. Coastal topography and adjacent mountains in the project site.

2.5 Geology and seismicity

2.5.1 Geology

The soil consists of (hard) limestones in the mountainous areas and alluvial deposits in the valleys. While the mountains provide a solid foundation for turbines, soft soils in the valleys may pose some risks of uneven soil settling and tilting of turbines. Also, liquefaction during earthquakes is a risk factor which must be investigated. The limestone in the project is hard and construction of roads may require blasting. However, the hardness of the material also has benefits: it will provide solid foundations for roads and platforms.

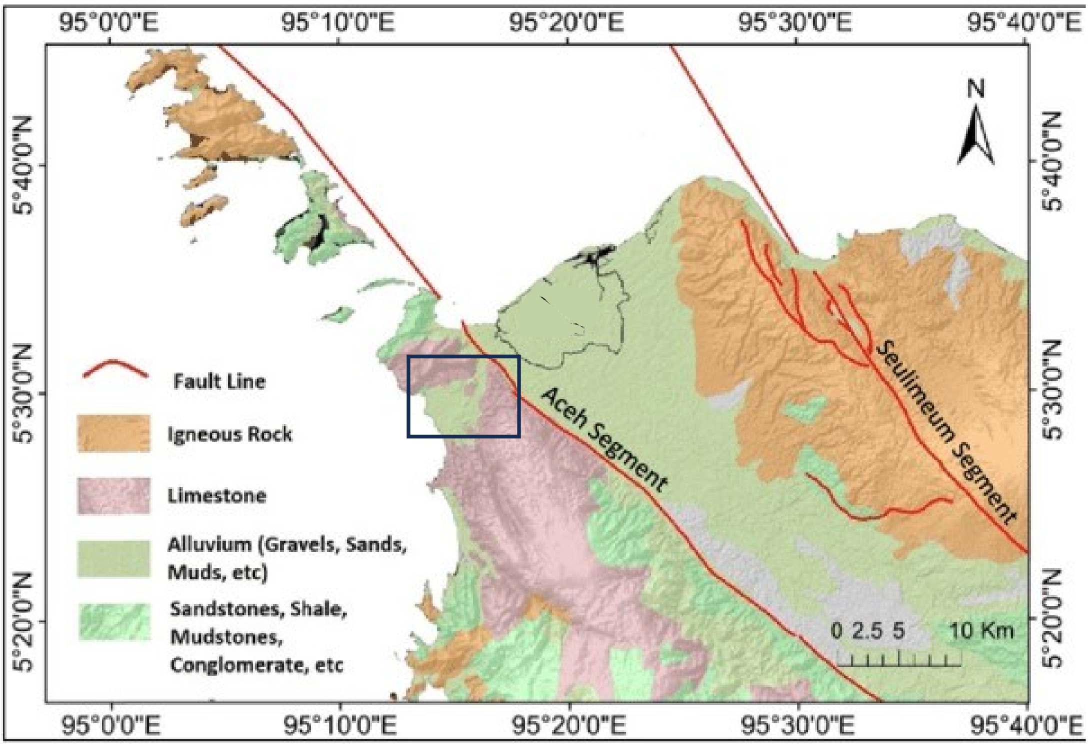

Figure 26. Geologic map of the Banda Aceh area. Source: The tectonic setting of northern Sumatra Aceh Province and geological map of Study area (Bennet et al. 1981).

The Land Movement Vulnerability Index provides an overview of the susceptibility of ground movement based on the slope steepness, type of soil, rainfall, seismicity, etc. Figure 27 visualizes the Land Movement Vulnerability Index of the soil in and around the WTG-area, as derived from Geological Disaster Mitigation Portal of the Ministry of Energy and Mineral Resources.

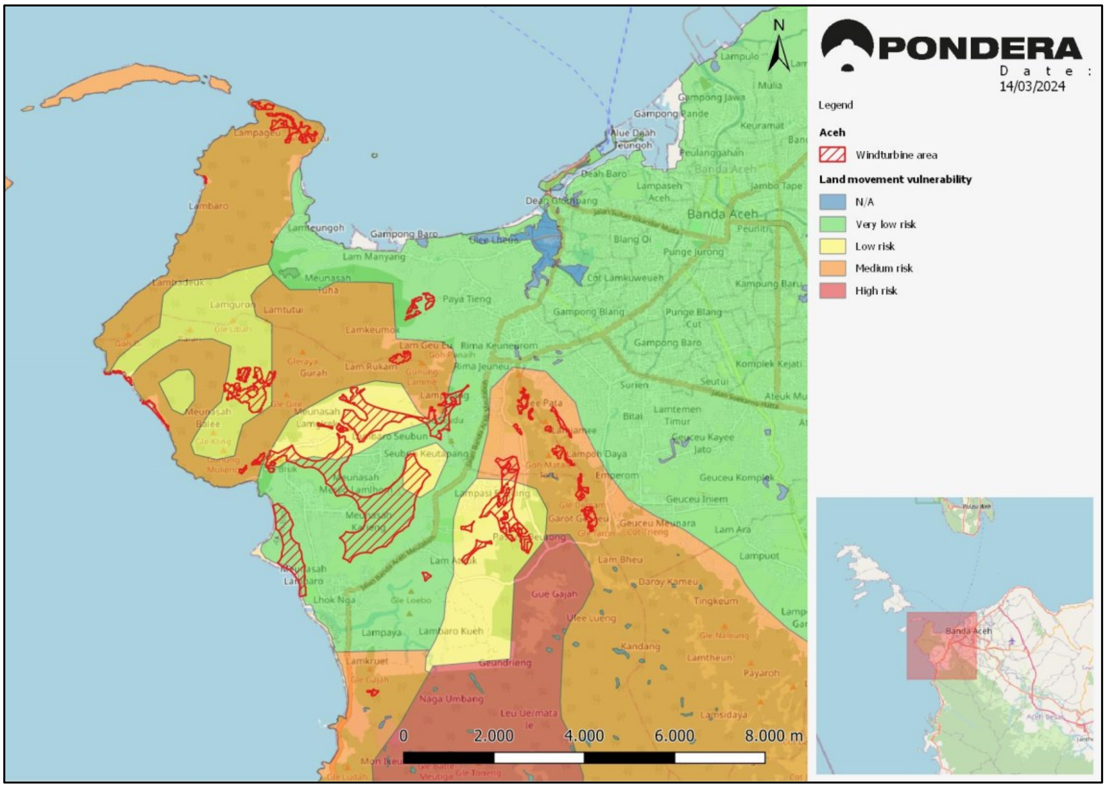

Figure 27. Land movement vulnerability index for Aceh.

According to the Land Movement Vulnerability Index, areas with steeper slopes are more vulnerable to land movement/landslides. In the feasibility stage, the stability of the slope needs to be investigated further by a geotechnical soil investigation, which determines several soil characteristics (e.g. shear strength, density, permeability etc.), and a following soil stability analysis in combination with the LiDAR-study for a more precise mapping of the topography.

2.5.2 Seismicity

The project site is close to an active fault line. The distance between wind turbines and the fault line is approximately 2-6 km. This is an active fault that carries a significant risk to the project area. This fault is present in the reference report of the Pusat Studi Gempa Nasional (PuSGeN), the national earthquake research center of the Ministry of Public Works and Housing (PUPR). Any structure in the area is subject to the building code SNI-03-1726-2019. The Peak Ground Acceleration' (PGA) at bed rock level for this project is based on this reference.

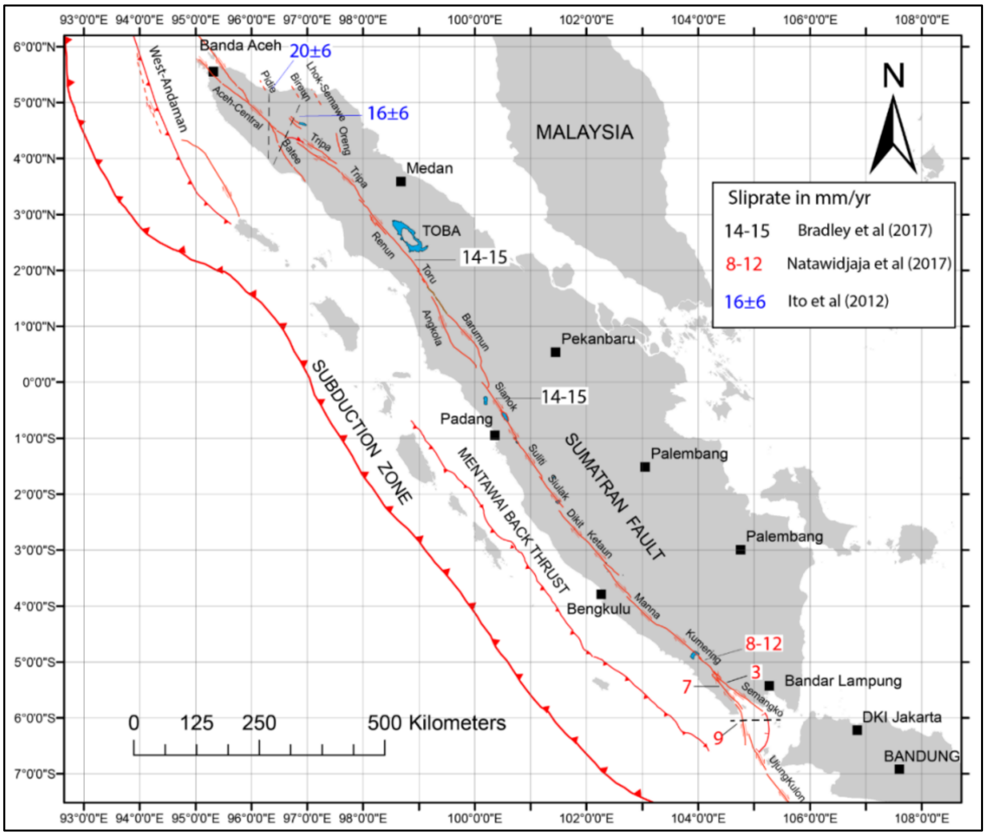

Figure 28. Generalized location of Great Sumatran Fault system, running along the entire length of the island.

The Indonesian national standard SNI-03-1726-2019 suggests building strong structures that have a maximum 2% chance of not performing well during their expected 50 years lifetime. This 2% chance means that the design should be able to withstand a very rare and strong earthquake with equivalent return period of 2,475 years. Based on the return period of 2,475 years the bed rock acceleration is 0.60 g, but the actual acceleration is also determined by soil types and topography. This corresponds to a Class VIII earthquake on the MMI scale. Figure 29 provides a visual representation of the earthquake risk level in and around the WTG-area.

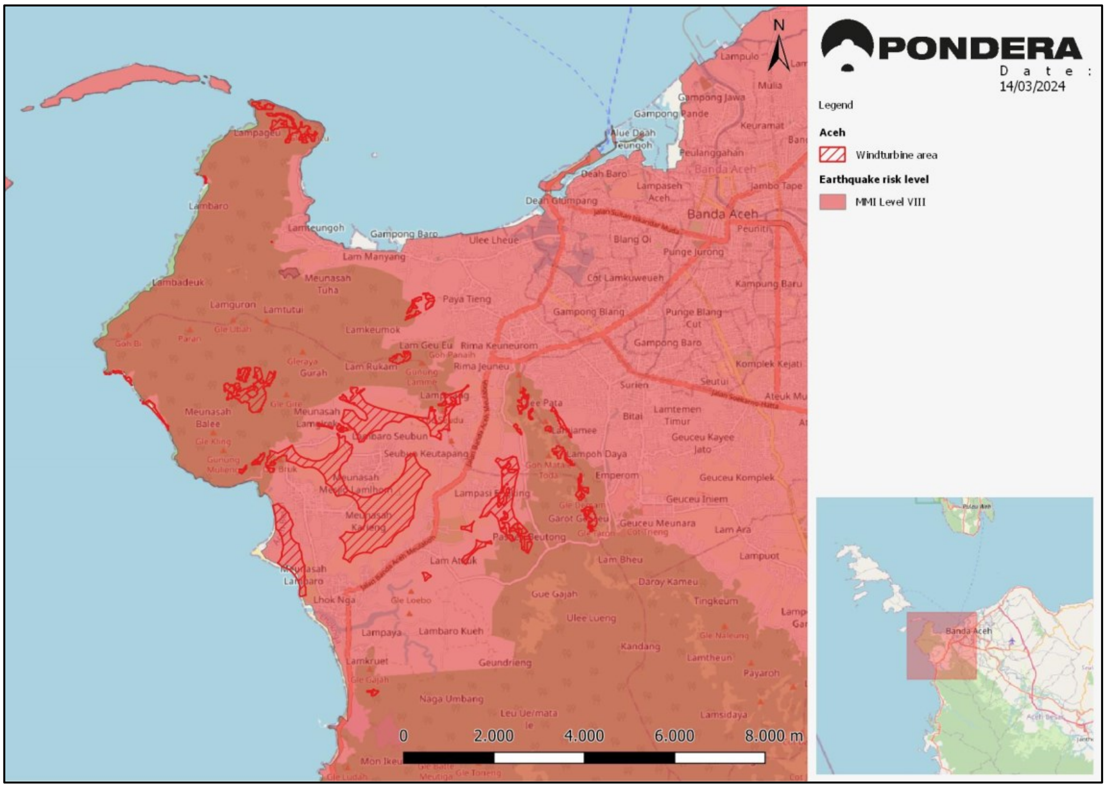

Figure 29. Earthquake hazard and risk level at Aceh Besar.

The MMI scale classifies earthquakes based on the impact on the surface rather than the energy released (like Richter's scale). The intensity of VIII is defined as:

"Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage is great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Motorists are disturbed."

This data gives just a general impression of the magnitude of earthquakes that can be expected. During the feasibility study the maximum expected peak ground acceleration should be calculated for more precise hazard assessment due to earthquakes.

2.6 Biodiversity, socio-economic and environmental conditions

2.6.1 General impression

Large parts of the project area are covered with forests, both primary and secondary. Several ‘species of concern’ can still be found in these forests. Smallholder farmers also use these forests, (illegal) loggers, hunters and some recreational entrepreneurs who have erected cabins for field trips. The forest on the northwestern tip of Banda Province has a protected status aimed at soil conservation (reducing risk of landslides). However, despite this protection, several slopes have been cleared for smallholder farms and recreational buildings.

Figure 30. Turbine sites and forested area in Aceh Province.

There is significant encroachment along the edges of the forests: increasingly more forested land is converted into agriculture and residential areas.

The central, low-lying area of the proposed wind is a mix of small villages, small farms, and rice paddy fields. The impact of a wind farm in this area will be a mix of biodiversity impacts (bird strikes) and environmental impacts on residents (noise, flickering).

2.6.2 Biodiversity and environmental impact

The spatial plan of the Aceh Besar Regency, as stipulated in Qanun Aceh No. 4/2013, and Decree Ministry of Environment and Forestry No. 580/2018, designates a significant portion of the Project Area as Protected Forest. Protected Forest areas are generally designated to protect the state of the forest, in order to maintain and protect ecological functions such as watersheds, flood prevention, erosion control, and maintaining soil fertility.

The Protected Forest status allows local community to utilize the area for plantations and wood collection. Power plant installations, transmission, and distribution of electricity, as well as the implementation of renewable energy technology are permitted in these areas, when this ‘cannot be avoided,’ under certain conditions[11]. While Indonesian regulations allow wind farms in the protected forests, this protected status and presence of species of concern may complicate international funding. International funding for development within protected forests is not granted easily. Influence on the environment and biodiversity should be limited as much as possible and any loss must be compensated.

In summary, the main impacts are:

Biodiversity impact:

- Habitat fragmentation (mainly roads and transmission lines)
- Opening of area: encroachment, illegal logging, squatting, hunting, farming
- Bird & bat strikes (turbines)
- Electrocution

Environmental impact:

- Erosion and landslide risks (roads, platforms)
- Increased turbidity in streams and rivers due to erosion
- Visual impacts of turbines
- Flickering & low-frequency noise

Observed flora and fauna:

In 2022, a biodiversity survey and desk study were conducted in the project area, showing the biodiversity values and risks. Below a brief summary is presented, indicating the values and risks based on the IUCN global red list category (International Union for Conservation of Nature's Red List of Threatened Species). The categorization is generally based on the rate of population decline, the geographic range, if the species has a small population size, if the species lives in a confined area or is very small, and if a quantitative analysis shows high probability of the species being extinct in the wild[12]. Ordered from the most to the least severely threatened, the categories are as follows: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), and Not Evaluated (NE).

It must be noted that the presented species have been observed in the wider Aceh Besar Regency area, which includes the project site. It is therefore not necessarily that these species can actually be found in the project site.

Potential species of concern in the Aceh Besar Regency are:

- 25 raptor species. Most species are protected under Indonesian law. Two of these species (Black-Winged Kite and Wallace's Hawk-Eagle) are designated by the IUCN as ‘vulnerable;’
- 5 species of storks, with 4 of them being ‘species of concern;

[11] Referring to Government Regulation 23/2021 and Regulation of the Minister of Environment and Forestry 7/2021.
[12] https://www.britannica.com/topic/IUCN-Red-List-of-Threatened-Species

- 22 other species (like Hornbills, Leafbirds, Ducks, Doves), of which 8 species have a (critically) endangered IUCN status;
- 18 swifts and swallow species. However, these species are abundant and not considered to be ‘species of concern’;
- 17 bat species, none of them having national protection status, but the Large Flying-fox is considered to be ‘endangered’ by IUCN.

While iconic mammals like the Sumatran tiger, orangutan and Sumatran elephant may not be present anymore in this area, several endangered mammals have been observed, such as sun bear, Sunda pangolin, long-tailed macaque and the Sumatran slow loris. Flying species are vulnerable to collisions with wind turbine blades, while the mammals are more vulnerable to habitat fragmentation and increased accessibility (facilitating hunters). Also, electrocution in power lines and substations is a common problem.

The impact on biodiversity and environment can be minimized when the following points are taken into account:

- Reuse as much of the existing infrastructure as possible, such as the existing powerline connection to the electrical grid and access roads;
- Avoid construction of roads and/or powerlines in such a way that the existing forest is cut up in separate sections, and use the same layout for road and the electrical grid between the turbines to avoid habitat fragmentation;
- Ideally only one access point should be made to enter the wind farm to limit the opening of the area for other activities such as illegal logging and hunting/poaching; and
- Limiting the amount of forest cleared around each wind turbine (generally between 50 to 100*100 m area). This space is used for the crane and storage. By using self-climbing cranes instead of traditional cranes this space can be minimized. With careful planning, temporary storage of wind blades next to the road instead of next to the turbine might also reduce the required area around the wind turbines.

As part of an Environmental and Social Impact Assessment, a biodiversity baseline study, risk assessment and mitigation measures should be conducted during the feasibility phase.

2.6.3 Social impact

The project site is located in Kecamatan (district) Lhoknga of the Aceh Besar Regency. The central section of the project site consists of a series of rural villages, surrounded by rice paddy fields. The population of this whole district is approximately 15,000 inhabitants. The number of residents in the project area is unknown. The beachfront of this district is an important source of income as it attracts many (local and regional) tourists.

The district mainly consists of a mix of smallholder farmers, shop-owners, and entrepreneurs operating small (beach) stalls and restaurants. There are also workers on various work levels who are commuting to nearby Banda Aceh city.

Figure 31. Villages in the project area, part of the Lhoknga District.

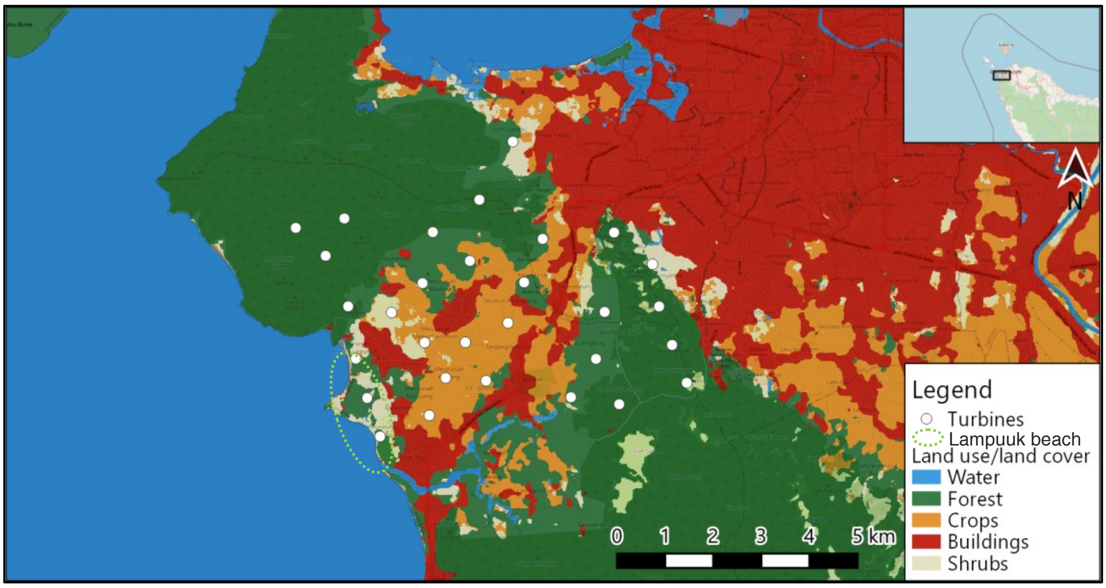

Figure 32. Land use map based on satellite imagery (ESRI/Sentinel 2, 2023). Villages/buildings and crops are located in the central valley directly surrounded by forests.

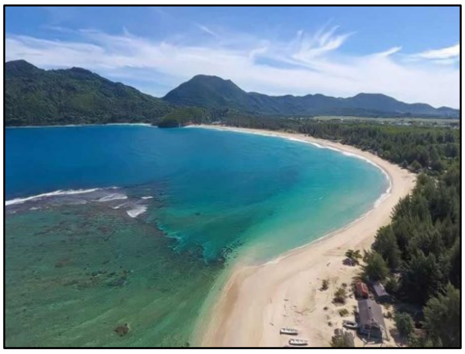


Figure 33. The beachfront in the Lampuuk coastal village (see the relative location in the previous figure).

It is hard to forecast the social (and economic) impacts of turbines in this area as there is no clear image of how the turbines will affect the scenery and whether beachgoers will be bothered by the presence of turbines (or even be attracted by them). The vicinity of turbines to villages may also result in (visual) impacts, but apart from such visual presence, limited social impact is expected. This impact can be divided into several aspects:

- Loss of agricultural land to be used for new roads or platforms;
- Temporary construction on roads, platforms and turbines (decreased accessibility and noise);
- Temporary transport of building materials and turbines (decreased accessibility and noise); and
- Long term visual impact of turbines in the area;

The next paragraphs provide an overview of the population and employment statistics in the regency.

Population

The graph of population and annual population growth rate is shown in Figure 34. It can be seen that the annual population growth rate in Aceh Besar Regency fluctuated in 2021-2023. The total number of inhabitants steadily increased within that same period.

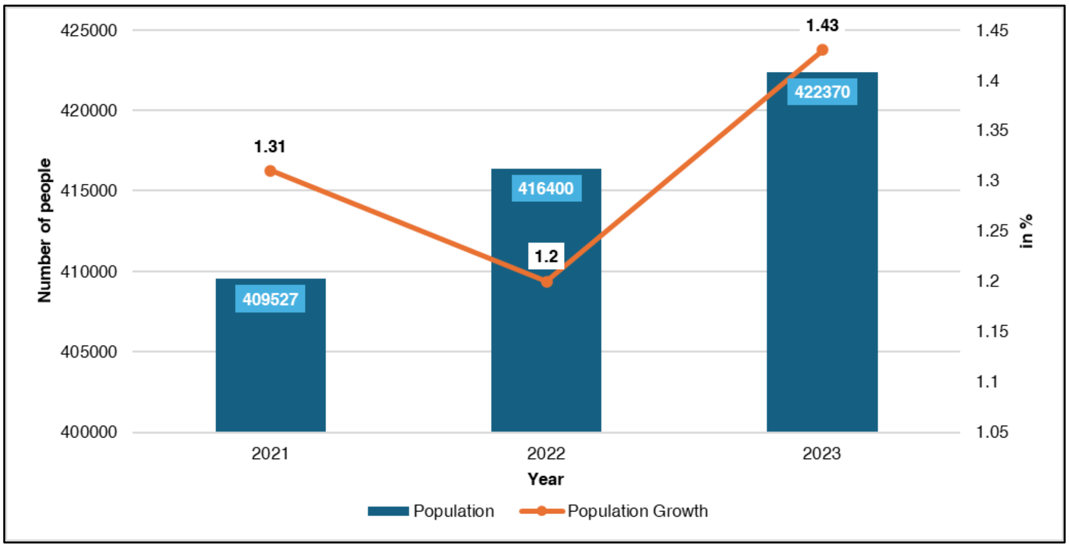

Figure 34. Population and annual population growth rate in Aceh Besar in 2021-2023 (Source: [Statistics Aceh Besar (bps.go.id)](https://aceh.bps.go.id)).

The regency's population pyramid is displayed in Figure 35. It is worth noting that the gender ratio was 1.02 in 2022.

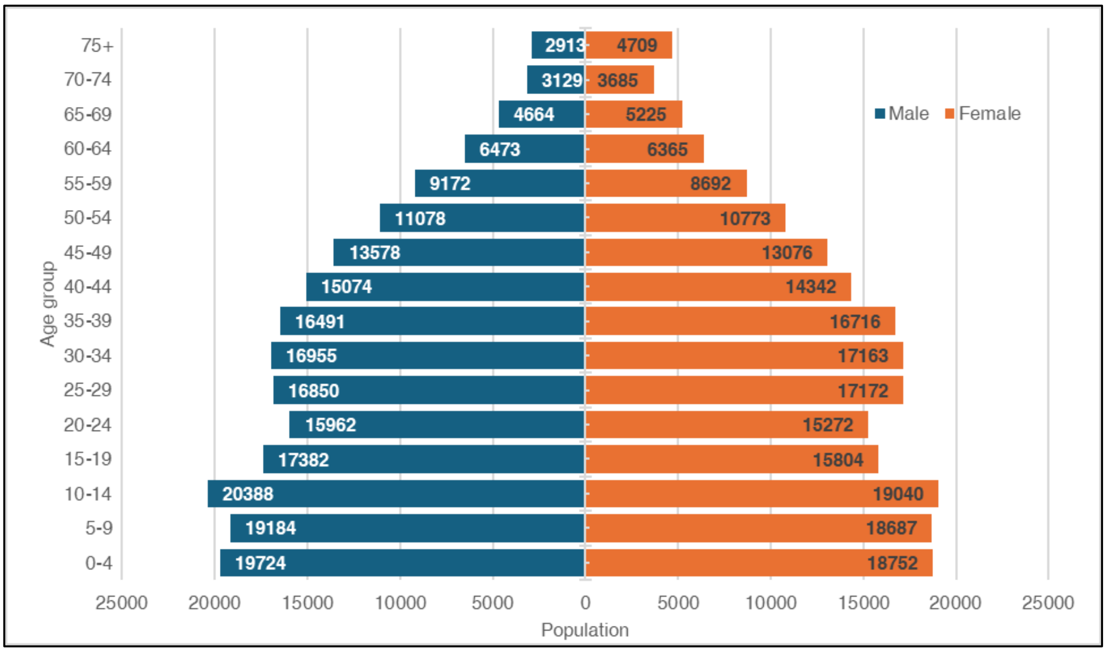

Figure 35. Population pyramid in Aceh Besar Regency in 2022 (Source: Statistics Aceh Besar (bps.go.id)).

Employment, education, and development

The labor force participation rate (TPAK) is an estimation of the proportion of the working-age population actively engaged in the workforce. The unemployment rate (TPT) is the proportion of the working-age population inactively engaged in the workforce. The TPAK in Aceh Besar in 2023 was 66.86%, increased from the previous year. The unemployment rate (TPT) in the same year was 8.17%, reduced from the previous year, as shown in Table 2.

Table 2. Labor force participation rate and unemployment rate in Aceh Besar in 2021-2023 (Source: BPS Provinsi Aceh).

Metric (in %)	Year		
	2021	2022	2023
Labor force participation	61.67	65.31	66.86
Unemployment rate	7.70	8.28	8.17

The number of workers according to highest education is presented in Table 3. In 2019, the workforce was dominated by workers who had senior high school as their highest education. In that year, the people who never go to school in 2019 was 521 people, not finished primary school yet was 5,658 people, went to primary school was 21,479, went to secondary school was 24,632, went to senior high school was 60,126, went to vocational school was 7,821, and went to university was 8,074.

Table 3. Workers according to highest education (people) in Aceh Besar in 2019 (Source: Statistics Aceh Besar (bps.go.id)).

Workers according to highest education (in people)	Male	Female	Total
Never/Not yet get into school	262	259	521
Not graduated yet from primary school	3,454	2,204	5,658
Primary school	15,388	6,091	21,479
Middle school	17,099	7,533	24,632
High school	45,249	14,877	60,126
Vocational school	6,428	1,393	7,821
University	2,946	5,128	8,074
Total	**17,437**	**12,272**	**29,709**

The pure participation rate in demographic data represents the ratio of enrollment for the age group corresponding to official school age in elementary or secondary levels, to the total population of the same age group in a given year. In the regency, the rates across different educational level increased in 2022-2023. These rates are shown in Table 4.

Table 4. Pure participation rate in Aceh Besar Regency in 2023 (Source: Statistics Aceh Besar (bps.go.id)).

Pure participation rate	Year	
Educational level	**2022**	**2023**
Primary school (SD)	99.13	99.61
Middle school (SMP)	85.11	88.50
High school (SMA)	72.07	78.18

The number of educational facilities across the different education levels in Aceh Besar Regency in 2019 is shown in Table 5.

Table 5. Educational facilities in Aceh Besar in 2019 (Source: Statistics Aceh Besar (bps.go.id)).

	Number of primary school	Number of Islamic primary school	Number of Islamic middle school	Number of Islamic high school	Number of high school	Number of vocational school
School units	211	50	32	25	44	10

The Human Development Index (HDI) measures human development achievements based on a number of basic components of quality of life, which is based on three dimensions:

- A long and healthy life (through life expectancy at birth);
- Knowledge (through indicators of literacy rates and average years of schooling), and
- A decent life (through indicators of people's purchasing power for a number of basic needs).

Human Development Index in Aceh Besar regency from 2017 to 2019 had slight increment from 72 to 73.55, as shown in Table 6.

Table 6. Human Development Index, Gender Empowerment Index, and Gender Development Index in Aceh Besar Regency in 2021-2023 (Source: Statistics Aceh Besar (bps.go.id) and BPS Provinsi Aceh).

Metric	Year		
	2021	2022	2023
Human Development Index	75.03	75.44	75.98
Gender Empowerment Index	48.11	47.65	47.20
Gender Development Index	94.93	95.22	95.29

Gender Empowerment Index (GEI) measures gender inequality in three fundamental dimensions:

- Economic participation and decision-making;
- Political participation and decision-making; and
- Power over economic resources.

GEI in the regency from 2021 to 2023 shows an overall decline, as shown in Table 6.

Gender Development Index is a measure of gender inequalities based on achievement in three fundamental dimensions:

- Health (through female and male life expectancy at birth);
- Education, (through female and male expected years of schooling for children, and female and male mean years of schooling for adults ages 25 years and older); and
- Command over economic resources (through female and male estimated earned income).

GDI in the regency from 2021 to 2023 shows a generally increasing trend, as shown in Table 6.

2.7 Transmission network design

2.7.1 Point of connection

Based on the location of the envisioned preliminary wind farm layout, the closest point of connection to the existing PLN grid has been determined. The Banda Aceh 150 kV PLN substation is selected for this, located south of the city of Banda Aceh. The aerial photo of this substation is included in Figure 36. Because the current study does not include a grid impact study, it is assumed that the wind farm can be connected to the existing grid, does not negatively influence the functioning of the grid and therefore no battery system is required. Furthermore, it is assumed that a busbar is available at the substation for connecting the wind farm at the substation.

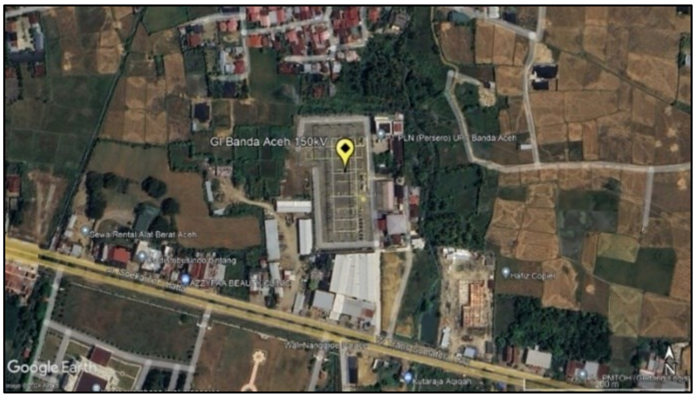

Figure 36. Location of the Banda Aceh 150 kV PLN substation. Source: Google Maps.

2.7.2 Schematic design transmission and distribution network

In Figure 37, the schematic design of the transmission and distribution network is illustrated. The 30 wind turbines will each have a 20 kV output (via a 5 MVA transformer per wind turbine) which is distributed via distribution cables. Per string of maximum 10 wind turbines, the generated electricity is distributed to one of the three substations within the wind farm. In these substations, the voltage is transformed to 150 kV. From the substation, the 150 kV cables come together and are connected to the powerhouse at the border of the wind farm. Overhead transmission lines transport the generated electricity from the powerhouse to the point of connection, the Banda Aceh substation.

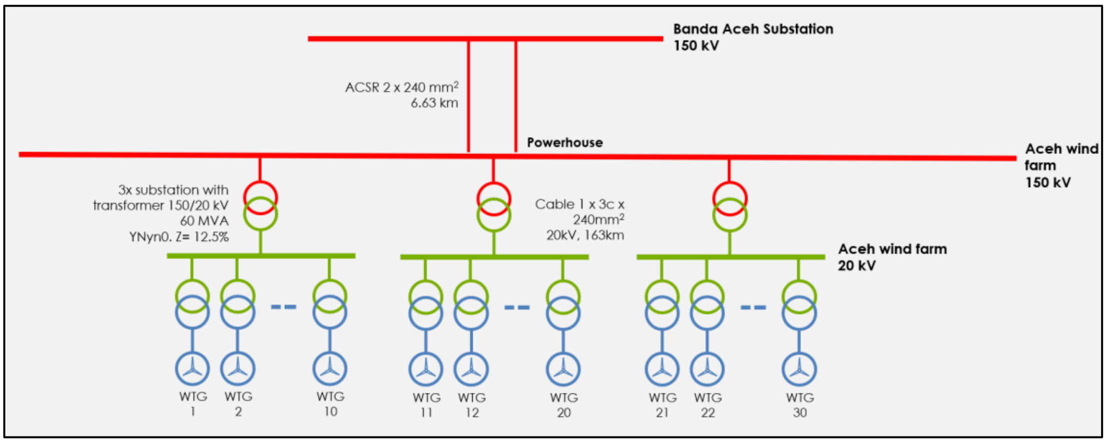

Figure 37. A schematic design of the transmission and distribution network at the envisioned Aceh Besar wind farm.

The overhead transmission line between the powerhouse and the PLN substation is assumed to be a straight line between both locations, covering 6 km as visualized in Figure 38. A total of 19 towers are planned with an intermediating distance between the towers of 340-450 m.

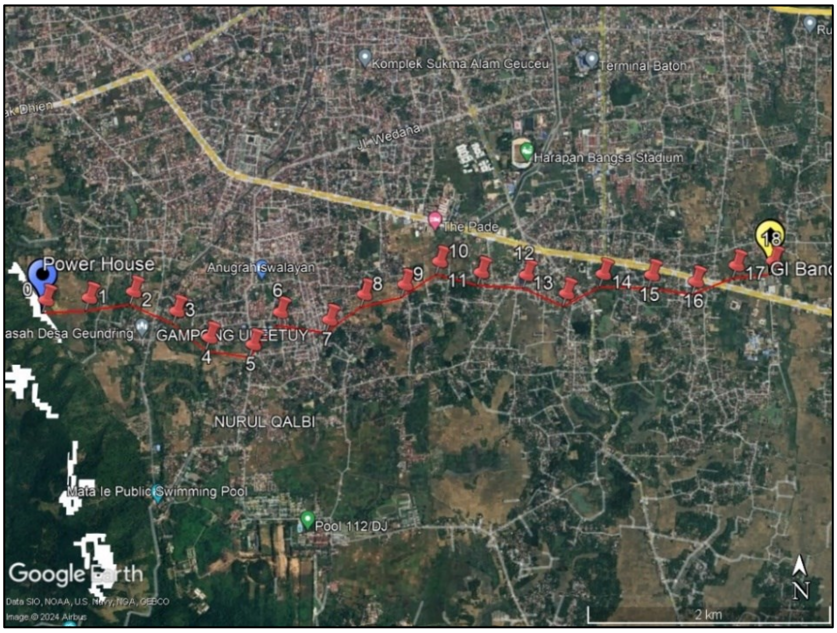

Figure 38. A schematic representation of the position of overhead transmission line between the powerhouse and the Banda Aceh substation.

2.8 Energy yield assessment

The energy yield is presented as an annual average and is therefore called the Annual Energy Production (AEP). The gross AEP is modelled by combining the calculated long term wind climate and the wind turbine specifications from the power curves.

For the energy yield assessment of the Aceh Besar site, the long-term wind speeds are determined based on the Large-Eddy Simulations (LES) with the model ASPIRE from Whiffle. The key strength of this large eddy simulation (LES) model is its ability to provide a detailed representation of complex flow patterns. This is important since the WTGs under consideration are partly placed in complex terrain. The LES has been performed and verified by a measuring mast for a nearby site. The simulation domain only partly overlaps with the Aceh Besar site. Therefore, virtual measurement masts from the LES are used as input for windPRO calculations.

The horizontal resolution of the LES is 100 m and the resolution in vertical direction is 40 m. The climatology is based on a representative year (2021).

Figure 39 shows the resulting climatology at the locations of the WTGs. The modeled long-term wind speed, which is averaged over all 30 WTGs at the planned hub height of 140 m, is 6.0 m/s. Wind turbine locations with wind speeds lower than 6 m/s are marked in red and orange colors. It must be noted that the mean wind speed in the Global Wind Atlas (GWA), is notably lower (2.6 m/s). Nevertheless, verification of the numerical models through measurements is essential, and here, the more intricate LES model is employed for further analysis.

The AEP is subsequently calculated based on the power curve of a 4 MW reference WTG with a rotor diameter of nearly 170 m and a hub height of 140 m.

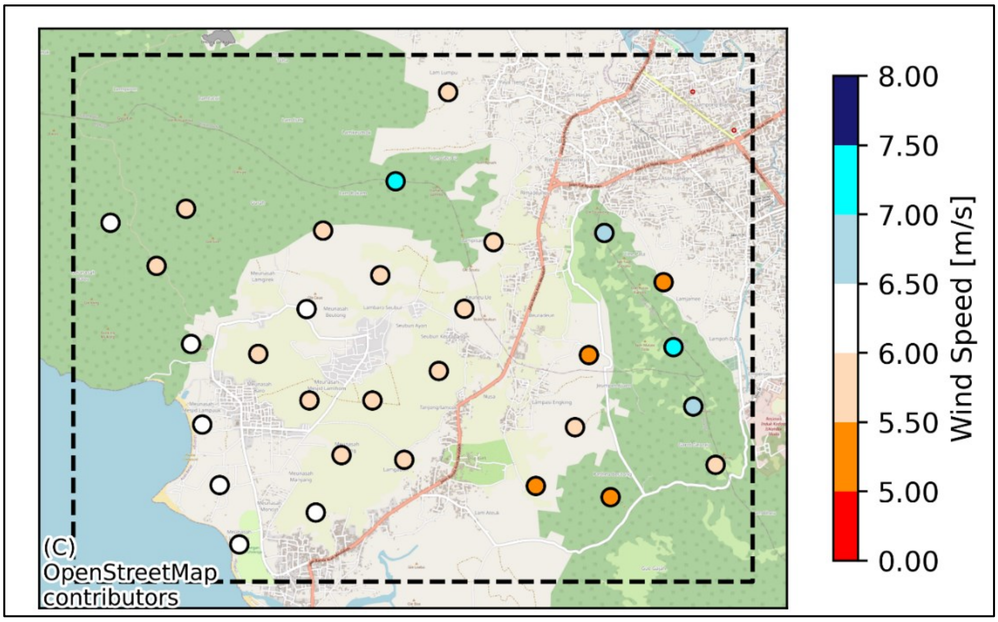

Figure 39. Long-term average wind speed results with the ASPIRE model at a height of 140 m at the turbine locations. The black-bordered circles represent the wind turbines, whereas the colors within the circles indicate the respective long-term average wind speed.

2.8.1 Energy losses

The net AEP is calculated by subtracting energy production losses from the gross AEP. These are losses due to a plurality of causes, such as wind turbine unavailability and performance related losses or electrical losses. These losses are determined either by calculations or by expert judgment and are included as percentage values of the AEP excluding wake losses.

In this report, the net AEP is displayed as the P50 AEP. The P50 value is a statistical level of confidence suggesting a value for AEP that may be exceeded with 50% probability. In other words, the P50 AEP is the average annual energy production that is expected over the wind farm's lifetime. Table 7 presents the estimated losses on the wind farm level.

Table 7. Expected losses on the wind farm level

Category	Types of energy loss	Amount	Explanation
Interaction	Wake losses [%]	8.6%	The wake effect is the aggregated influence on the energy production of the wind farm, which results from the changes in wind speed caused by the downwind impact of the wind turbines on each other. The wake losses are modelled using the standard NO Jensen (RISØ/EMD) model (PARK2 – 2018 version) in windPRO, resulting in an overall wake loss of 8.6%.
	Blockage losses [%]	0.0%	Wind farms do not only interact with downstream wind speeds (i.e. the wake effect), but also interact with decreased upstream wind speeds. This upstream wind speed reduction is called the blockage effect. The Self Similar model by

Category	Types of energy loss	Amount	Explanation
			Forsting (2016)[13] with linear parametrization is used to calculate blockage. 0% blockage is expected for the layout.
Availability	Non-availability [%]	4.0%	This production loss concerns the periods of a wind turbine that it is not in operation due to maintenance, malfunctioning and re-orientation of the nacelle. For onshore wind farms with more than 5 WTGs, 4.0% loss is considered.
	Balance of Plant [%]	0.1%	Balance of Plant losses occur due to the unavailability of the transformer station or access roads and therefore hinder normal wind farm operation.
	Grid downtime [%]	0.5%	Grid downtime losses are caused by grid non-availability from grid operator.
Performance	Power curve losses [%]	2.0%	Performance losses are the result of sub-optimal operation of the wind turbine. This occurs when wind turbines are operational outside the design conditions of the power curve. A conservative 2.0% performance loss is assumed since no site-specific power curve is available.
	High wind hysteresis [%]	0.5%	At the cut-out wind speed, wind turbines are switched off due to safety precautions. The calculation model assumes that the wind turbines are fully operational until cut-out wind speed and are turned off from exactly that point. In reality, if the wind speed fluctuates around the cut-out wind speed, the wind turbine will shut down until the wind speed is below the re-cut in wind speed. A loss of 0.5% is assumed.
	Yaw misalignment [%]	0.0%	Yaw misalignment losses are caused by the inability of the WTG to align itself completely with the actual wind direction and therefore losing production potential. The reason could be an older operating system that is not able to measure the current wind direction accurately. It is assumed this will not occur.
Electrical	Electrical losses [%]	2.0%	Electrical losses in power cables occur due to cable resistance, which increases the temperature of the cables and results in these power losses. A conservative value of 2.0% is assumed.

[13] Meyer Forsting, A. R., Troldborg, N., & Gaunaa, M. (2016). The flow upstream of a row of aligned wind turbine rotors and its effect on power production. Wind Energy, 20(1), 63–77.

Category	Types of energy loss	Amount	Explanation
	Transformer losses [%]	1.0%	The WTG transformers consume energy as the voltage level is increased. Since the transformer losses are not incorporated in the P-V curve, a loss of 1.0% is assumed.
	Electricity consumption WTGs [%]	0.1%	Wind turbines need electricity to support operational activities such as software systems. A 0.1% energy loss is assumed.
Environmental	Shutdown due to icing, lightning etc. [%]	0.3%	Shutdown is a necessary safety precaution during cold periods when ice accumulates on the blades or during thunderstorms. No icing is expected at this site. Losses due to lightning of 0.3% are assumed.
	Blade degradation [%]	1.3%	Over time, the aerodynamic efficiency of wind turbine blades decreases due to degradation. For onshore wind turbines, this is mainly due to organic matter, dust particles, and other particulate matter accumulating on the blade. These effects accumulate over time. 0.1% annual degradation losses are assumed. Over a lifetime of 25 years, 1.3% losses are expected.
	High and low temperature [%]	2.0%	Temperature de-rating occurs when the wind turbine operates outside of the operating temperature range. The losses are expected to be 2.0%.
	Tree growth & felling [%]	0.0%	The ridges to the North and to the East of the wind turbine site are covered by forest and changes in tree height or tree felling might lead to different roughness and changes in wind speed. However, because no substantial tree felling is expected, in this case no additional loss is accounted for.
Curtailment	Grid curtailment [%]	0.0%	Losses due to grid curtailment are not considered for this wind farm.
	Noise curtailment [%]	0.0%	Wind turbines operate in noise-reduced power modes to minimize noise levels on nearby homes. Since this site is located in a remote area, no losses are expected.
	Shadow flicker curtailment [%]	0.0%	Shadow flicker is the effect when rotor blades periodically cast a shadow over a certain area. Shadow flicker curtailment is introduced with the purpose of mitigating significant effects on houses. Since this site is located in a remote area, no losses are expected.
	Bird/bat mitigation [%]	0.0%	A full analysis of the potential habitats of protected birds and/or bats is to be conducted in the feasibility study. At this moment the losses are assumed to be 0.0%.
	Wind sector management [%]	0.0%	To safeguard the expected WTG lifetime a so-called Site Assessment study is undertaken by the WTG manufacturer. When this Site Assessment shows exceeding loads on WTG

Category	Types of energy loss	Amount	Explanation
			components, based on certain climatic conditions, there is a need to change the WTG’s normal operation mode to an alternative program. This often includes the application of reduced power modes which often results in production losses. At this moment it is assumed to be 0.0%.
Sub-total non-interaction losses [%]		**13.0%**	The accumulation of all of the above-mentioned losses, excluding wake losses. Based on 1-(1-loss A)*(1-loss B)*(1-loss C)*…etc.
Total losses [%]		**20.5%**	The accumulation of all of the above-mentioned losses, including wake losses. Based on 1-(1-loss A)*(1-loss B)*(1-loss C)*…etc.

2.8.2 Energy yield including uncertainties

Incorporating model uncertainties leads to an increase of the reliability of wind resource assessment. Typically, the P90 AEP is used to express the impact of uncertainties. The P90 is a statistical level of confidence suggesting an AEP value that may be exceeded with 90% probability. When a normal probability distribution is assumed, the Pxx value is found through the following formula:
$P_{90} = P_{50} * (1 - 1.28*\sigma)$. The uncertainty [in %] is expressed as σ.

Here we assume a conservative uncertainty to be 20% since the calculations are purely based on numerical models and no measurements have been performed on-site at this stage. The resulting P90 value is given in Table 8.

Table 8. Energy yield for all 30 WTGs at the Aceh Besar wind farm

Parameter [Unit]	Amount
Number of new WTGs	30
Rated Power per WTG [MW]	4.0
Total rated Power [MW]	120.0
Rotor diameter [m]	~170
Hub height [m]	140
Air density [kg/m3]	1.151
Wind speed [m/s]	6.0
Gross result [MWh/yr]	398,549
Gross results including wake effects [MWh/yr]	365,114
P50 [MWh/yr] [14]	**317,543**
P90 (25 yr) [MWh/yr]	**236,154**
P50 [hrs/yr]	**2,646**
P90 (25 yr) [hrs/yr]	**1,968**

2.8.3 Power output variations

In Subsection 2.8.2 we have provided an estimate of the P50 annual production, equal to 317,543 MWh per year. Previously, during the first wind resource assessment in Subsection 2.2.2 we have shown that for this site there is a large variation in wind speed throughout the year, with the highest wind speeds during the summer months. This variability has a direct effect on the wind farm's total power output at specific moments of the year.

[14] Note that the P50 value is based on the LES calculation with a mean wind speed higher than the Global Wind Atlas. Both models are based on the underlying ERA5 model data. The uncertainty in the AEP will be reduced once on-site measurements are performed. Until that time, the results of this study shall be interpreted with careful discretion.

Figure 40 shows the average wind farm power output for each month, subdivided into the hours over a full day. The input data for this figure is derived from the ASPIRE modelling combined with the EMD-WRF average variability in wind speeds throughout the year.

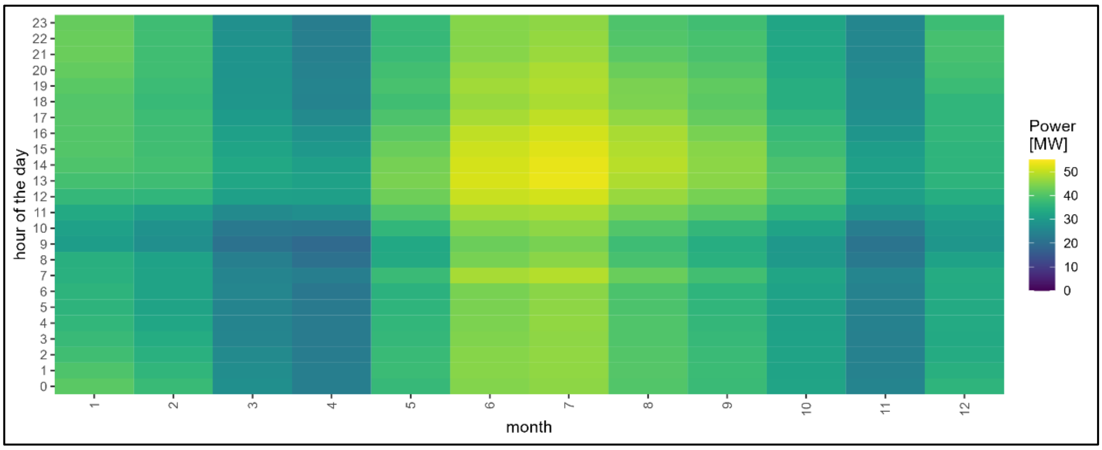

Figure 40. Overview of the monthly variation of wind farm average power output per hour of the day based on the P50 values from Subsection 2.8.2 in combination with the monthly and hourly variation in wind speed from EMD-WRF (see also Figure 8)

2.9 Business case assessment

2.9.1 Component assumptions

In order to determine the business case for the wind farm, it is necessary to quantify the input cost parameters and define the assumptions used. This is categorized in:

- Preparation works
- Wind turbines
- Civil works
- Electrical work
- Operational expenditure

In the following subparagraphs each of the above categories is further explained.

Preparation works

The following preparation works should be executed before the start of a large part of the design works and definitely before the start of the construction. The cost for these preparation works is included in the business case:

- Pre-feasibility study
- Full feasibility study
- Grid impact assessment
- Permit application

- Surveys
    - Topographical
    - Port evaluation
    - Road conditions
    - Geological
    - Geotechnical
    - Environmental
    - Social
- Wind measurements (3 met masts for 1 year)
- Land acquisition, assuming IDR 200,000 /m^2 + 5% tax for low-quality soils, IDR 520,000 /m^2 + 5% for moderate fertile areas, to be used for:
    - New road surface
    - Rotor diameter surface
    - Road upgrade surface
    - Powerhouse and substation surface
    - Transmission tower surface

Wind turbines

The quantities which are relevant for the installation of 30 wind turbines at the wind farm are shown in Table 9.

Table 9. Wind turbine quantities relevant for the envisioned Aceh Besar wind farm.

Main component	Quantity
Nacelle incl. generator (4 MW)	30 pcs
Blade (85 m)	90 pcs
Tower segments (total 140 m height)	180 pcs

Furthermore, the following (cost) assumptions are used in the business case:

- A Chinese wind turbine manufacturer is used as reference turbine. This manufacturer has so far, a limited track record outside of China but can offer competitive pricing. Quality assurance through client references, international certification, factory acceptance tests, site acceptance tests, quality guarantees, etc. are necessary.
- All wind turbine components are shipped from China to the Port of Malahayati (Medan) and via road transport brought the wind farm site;
- Import duty of 5% apply for the generator and blades, and 15% for tower parts are assumed[15];
- The cost includes transport, crane rental, installation, and commissioning.

[15] Assumption based on a report by PwC titled *Power in Indonesia: Investment and Taxation Guide* (August 2023, 7th Edition)

Civil works

The quantities which are relevant for the civil works necessary for the installation of 30 wind turbines at the wind farm are shown in Table 9.

Table 10. A list of assumptions on civil works components.

Main component	Sub-component	Quantity
Roads (incl. design, materials, transport, labor)	Construction of new gravel road within the wind farm site	23 km
	Upgrading existing road	12 km
Strengthening bridges (incl. design, materials, transport, labor)	Concrete bridge strengthening	7 bridges
	Steel bridge strengthening	1 bridge
Foundations (incl. design, materials, transport, labor)	Anchors (72 per foundation)	2,160 pcs
	Anchor cages	30 pcs
	Concrete (230 m^3 per foundation)	6,900 m^3
	Steel (35 tons per foundation)	1,050 tons
Crane hardstands (incl. design, materials, transport, labor)	Crane hardstands (50 x 100 m) using gravel	30 hardstands

Furthermore, the following (cost) assumptions are used in the business case:

- Civil works are including design, materials, transport and labor;
- Large parts of the road from port to site are in good condition. Some sharp curves are located within the city of Banda Aceh. It is expected that most of the larger bridges need no strengthening, as they are built after the tsunami of 2004 and probably strong enough. Within the site some existing road can be used. Especially in the mountains, new roads will have to be constructed.
- There is a risk of substantial (hidden) additional costs. For example, the need to strengthen offloading quays in the port or to create a large lay-down area due to logistical challenges at the port. This requires further analysis in the subsequent feasibility study;
- Cost amounts used in the business case are based on best practices, desk research and a limited site visit which entails significant uncertainty in the cost assumptions.

Electrical works

The following limited bill of quantities for the electrical works has been determined for the wind farm in Table 11.

Table 11. A list of assumptions on the electrical works components.

Main component	Sub-component	Quantity
Transmission line (19 km, 48 towers)	Transmission towers	19 pcs
	Conductor	1 set
	Insulator and Fitting; Type Normal	1 set
	ACSR Hawk 240 mm^2 cable	1 set
	GSW 70 mm^2 cable	1 set
	OPGW 70 mm^2 cable	1 set
Powerhouse (1 for the entire wind farm)	Incoming MV switchgear	3 pcs
	LV switchgear	1 pc
	DC Supplies	1 pc
	Lightning protection	1 pc
	2x3C 300 mm cable	567 m
Wind farm electrical works (between the powerhouse, substations and wind turbines)	Transformers 20kV (5 MVA)	30 pcs
	Switchgear	30 pcs
	MVAC Cable (1 x 3c x 240) 50 and 300 meters	163 km
	Earthing System	1 set
	Control & Monitoring System	1 set
	Fire Protection System	1 set
	Hydrant system	1 set
	Water Facility (Clean and Dirty)	1 set
Substations (three for the entire wind farm)	Transformer 150/20kV 30 MVA	3 pcs
	Neutral Grounding Resistor	3 pcs
	Switchyard	1 pc
	In/outgoing bays, coupler, busbars, Panel RCP	3 sets
	LV switchgear	1 set
	SAS/ SCADA system	1 set

Furthermore, the following (cost) assumptions are used in the business case:

- Electrical works are including design, materials, transport and labor;
- Because the current study does not include a grid impact study, it is assumed that the wind farm can be connected to the existing grid, does not negatively influence the functioning of the grid and therefore no battery system is required; and
- It is assumed that a busbar is available at the substation for connecting the wind farm at the substation.

Operational expenditure

The following expenses are expected to be incurred when the wind farm becomes operational (also referred to as CoD) until the end of the design lifetime of the wind farm (25 years):

- Maintenance and service cost of the wind turbines, civil works and electrical works
- Business operation cost, e.g. asset management, financial management, PPA management, etc.
- Compensation for the use of forest for approximately 50% of the project location, assuming IDR 2 million/ha/year
- Insurances (e.g. machine breakdown insurance, third party liability)

2.9.2 Cost assumptions

In the table below, the cost assumptions per cost component are listed which serve as input for the business case. The business case distinguishes between DEVEX (development expenditure, before CoD), CAPEX (capital expenditure) and OPEX (operational expenditure). Because of the uncertainty and limited information on which the cost assumptions are based, a cost range (as a percentage of the baseline cost) is defined for each of the cost components. The cost range spread depends on the uncertainty of the cost assumptions.

For example, for civil works, the cost assumptions have high uncertainty because of the effect that physical surveys have on the design decisions and therefore construction price. The wind turbine cost has smaller spread because the uncertainty is mainly caused by global fluctuations, not by design decisions (it is a serial product).

The accumulation of the cost ranges eventually leads to the lower-, baseline-, and upper bound total investment cost. From this a cost per MW is calculated, which is an indication how high the investment for this particular wind farm is compared to the global average (being in 2024 USD 1.3M / MW[16]) and to the other 7 locations.

[16] Source: https://www.iea.org/data-and-statistics/charts/actual-and-forecast-onshore-wind-costs-2016-2025

Table 12. Cost assumptions per cost component.

Cost component	Baseline cost including VAT	Comment	Cost range
Preparation works	USD 3,245,000	DEVEX: Prior to Financial Close	90% - baseline -120%
Project management	USD 8,442,000	DEVEX: Until CoD	Baseline
Wind turbines	USD 83,619,000	CAPEX: Including transport and installation	90% - baseline -120%
Civil works: foundations	USD12,021,000	CAPEX	80% - baseline -150%
Civil works: roads	USD 13,010,000	CAPEX	80% - baseline -150%
Civil works: crane hardstands	USD 2,825,000	CAPEX	80% - baseline -150%
Electrical works	USD 29,734,000	CAPEX	90% - baseline -120%
Land acquisition	USD 24,309,000	CAPEX	90% - baseline -150%
Risk contingencies	USD 13,508,000	DEVEX + CAPEX	Baseline
Lower bound total investment cost (DEVEX + CAPEX)	**USD 171,123,000**	**Investment cost per MW: USD 1,423,000**	
Baseline total investment cost (DEVEX + CAPEX)	**USD 190,803,000**	**Investment cost per MW: USD 1,590,000**	
Upper bound total investment cost (DEVEX + CAPEX)	**USD 240,249,000**	**Investment cost per MW: USD 2,002,000**	
Baseline operational expenditure (OPEX)	**USD 3,577,000 / year**	**Operational cost per MW / year: USD 29,000**	

2.9.3 Financial parameters

The following financial parameters assumptions are applied in the business case:

- The wind farm has a design lifetime of 25 years;
- A depreciation period of 25 years;
- The construction starts in the year 2028,
- The procurement of the wind farm components is assumed in 2026, for which a yearly indexation of 3% is used on the 2024 price level;
- The operational expenditure is to be indexed at 5%;
- A gearing of 70% loan, 30% equity;
- The debt tenure is 10 years, annuity repayment structure;
- The interest rate on the debt is 9.0%;
- Property taxes and company taxes are included;
- All costs are including VAT;
- The project management cost on behalf of the developer until CoD is assumed to be 5% of the total cost;
- A risk contingencies budget is assumed to be 8% of the total cost including project management cost;

- After 25 years the remaining residual value of the wind farm is transferred at USD 0 to PLN;
- The tariff structure in accordance with Presidential Regulation 112/2022 is used. This defines the following:
  - Ceiling tariff per kWh in year 1-10 for wind farms >20 MW = 9.54 x location factor (being 1.1 for Aceh Besar) = USD cent 10.49 / kWh
  - Ceiling tariff per kWh in year 11-25 for wind farms >20 MW = USD cent 5.73 / kWh
  - The business case assumes a PPA on the above ceiling tariffs. In practice, it is likely that a developer must negotiate with PLN about this which will lead to a lower PPA tariff.
  - No separation in components for the tariff structure is used, i.e. on O&M and electrical works.
- In the PPA no Annual Contracted Energy (ACE) applies.

2.9.4 Results of business case assessment

Based on the calculated energy yield in Subsection 2.8.2, the cost assumptions as listed in Subsection 2.9.2, and the assumed financial parameters in Subsection 2.9.3, the business case of the wind farm has been determined for the lower-, baseline- and upper-bound cost scenario. This leads to the following results:

Table 13. Results business case assessment.

Business case outcome	Lower bound cost scenario	Baseline bound cost scenario	Upper bound cost scenario
Project (before taxes) Internal Rate of Return (IRR) at P50	11.25%	9.25%	5.52%
Average Debt Service Coverage Ratio (DSCR) at P90	0.90	0.82	0.67
Net profit at P50 over 25 years	USD 119,250,000	USD 99,468,000	USD 50,970,000

3 Conclusion and Recommendations

Based on the conducted analysis, it is concluded that the overall techno-economic viability of a wind farm in Aceh Besar region requires improvement. The main cause for this is the lower wind speeds than expected at specific wind turbine locations. Although the initial wind resource assessment only included areas with wind speeds above 6 m/s, during the wind modelling stage the wind speed at some wind turbine locations turned out to be below this number (see Figure 39). This is likely caused by the effect of the topography on the wind characteristics, which is to a lesser extent notable when creating a wind speed map based on Global Wind Atlas. Based on the wind modelling it seems that the most promising wind speeds are found on the northeastern ridge, near the coast and in the mountainous area in the north western part of the site (still to be validated by wind measurements). We recommend reconsidering the site layout during a follow up study, in which the focus is on these specific areas. This could lead to a wind farm size of approximately 50 MW, with likely an improved business case outcome.

Aside from the lack of wind resources at several wind turbine locations, the envisioned wind farm does entail other risks that should be taken into account by the developer and investor. This can be summarized in the following non-limitative risk list, including the respective recommendation of mitigating measures:

- **Wind resource:** There is still significant uncertainty on the wind resource in the area as determined by this study. The variety in outcome between the different models shows that validation of the wind resource early in the development process is vital. We recommend at least to place three met masts for data gathering for at least one year, see Figure 41. In the background of the figure are the wind speeds from the Global Wind Atlas (GWA) shown. The elevation is shown with contour lines. The red dots indicate the wind turbine locations. The yellow icons show the global positioning of recommended met mast locations.

  The locations of the met mast are described as follows: one in the mountainous northwestern part, one in the flat terrain and one on the eastern ridge of the WTG area. Especially on the ridge it is recommended to additionally measure with an ultrasonic 3D anemometer, as on the ridge the turbines will most likely experience up and downdrafts. Using the ultrasonic 3D anemometer the horizontal velocity and vertical velocity will be measured. The ultrasonic 3D anemometer should also be considered in the northwestern area.

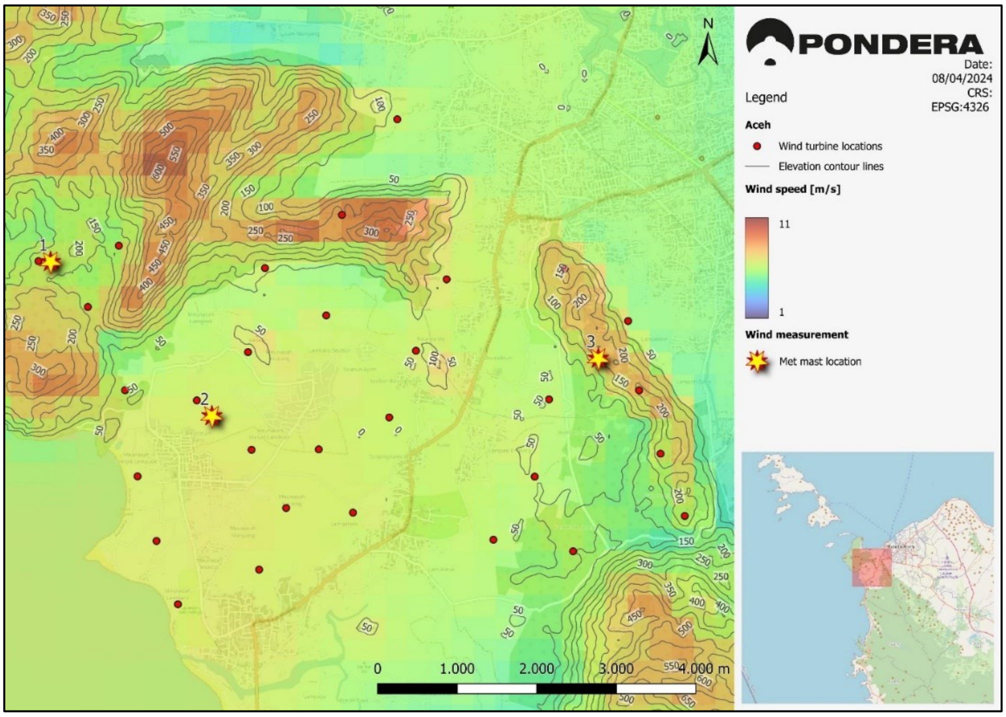

Figure 41. Recommended met mast locations

- **Land use and permitting:** As can be derived from Figure 32, the wind farm is planned in roughly a 70/30 split between forest area and crops area. For the former area, it will be mandatory for the future developer to obtain specific approvals and permits from the authorities; whereas for the latter area, a deal will need to be struck with the landowner to either acquire or lease the land. Considering these required actions, it is also important for the developer to assess the land use / ownership in greater detail early on in the development process. The developer is recommended to firstly start consulting the authorities about the willingness and possibility to issue these approvals and permits, and to approach the relevant landowners about the possibility of arriving at an agreement on the land.

- **Transport:** A limited accessibility analysis has been conducted for this prospectus, concluding that Malahayati Port is the most suitable starting point for the transport over land. To ensure that the port in Malahayati is suitable for offloading and storing the wind turbine components, a more extensive assessment needs to be conducted on the port which could entail a consultation with the port owner. Large parts of the road from the port to site are in good condition. Some sharp curves are located within the city of Banda Aceh. It is expected that most of the larger bridges need no strengthening, as they were built after the tsunami of 2004 and are likely strong enough. Within the site some existing road can be used. Especially in the mountains, new roads will have to be constructed. A more extensive logistical survey is recommended to be conducted as part of the future feasibility study to obtain more details of the required infrastructure (adjustments).

- **Geology:** Based on the level of the study conducted for this prospectus, there are still significant uncertainties included in the design and construction of the foundations, roads, and crane hardstands, due to the geological circumstances and the impact of these circumstances. Therefore, it is recommended to further investigate the stability and capability of the soil to carry wind turbines. This need to be determined through a geotechnical soil investigation, which determines several soil characteristics (e.g. shear strength, density, permeability etc.), and a following soil stability analysis in combination with the LiDAR-study for a more precise mapping of the topography.

- **Seismicity:** The envisioned wind farm is planned in an area with earthquake risk (similar to many other locations in Indonesia). During the feasibility study, the maximum expected peak ground acceleration should be calculated for more precise hazard assessment due to earthquakes. The study should also look at the possible ways to mitigate the identified earthquake risk. The foundation design should at least comply with the international standards for mitigating earthquake risks.

- **Environment:** Although the wind farm location is not a densely populated area, there will be visual impact on the area because of the use of wind turbines with a tip height of 200m. The presence of this wind farm could cause opposition from local stakeholders and environmental groups on the wind farm development. Therefore, it is recommended to involve these stakeholders early in the wind farm development, to identify and mitigate specific objections from each stakeholder.

- **Flora and fauna:** In 2022, a biodiversity survey and desk study were carried out in the project area, showing several potential species of concern (including raptor, stork, swifts and bat species). While iconic mammals like the Sumatran tiger, orangutan and Sumatran elephant may not be present anymore in this area, several endangered mammals have been observed, such as sun bear, Sunda pangolin, long-tailed macaque and the Sumatran slow loris. It is likely that the wind farm development will have an effect on biodiversity. Also to be considered, international funding for development within forests is not granted easily. Consequently, it is advised that as part of an Environmental and Social Impact Assessment, a biodiversity baseline study, and risk assessment and mitigation measures are carried out during the feasibility study.

- **Grid connection and PPA:** The wind farm is designed to be connected to the PLN grid. This assumes that the grid can integrate 120 MW of wind energy (with variable output), and that the substation in Banda Aceh is suitable to facilitate the wind farm's grid connection. These assumptions should be verified during the feasibility study. Additionally, the current result of business case assessment is based on the assumption that the PPA uses the ceiling electricity tariff as stipulated in Presidential Regulation 112/2022, and that no Annual Contracted Energy (ACE) is applied. The actual PPA conditions depend on PLN and on how the tender process is set-up. An early alignment with PLN on these PPA conditions and tender process set-up is recommended.

Based on the above list of risks and recommended mitigating measures, and as the subsequent step in the wind farm development, it is recommended to prioritize the execution of on-site wind measurements to validate the actual wind speeds at the area. In parallel with the measurements, it is important to start engaging and aligning with the relevant stakeholders and local authorities about their willingness to collaborate in wind energy development at this location.

4 Disclaimer

This wind farm prospectus has been written with due care based on assessments conducted by four experienced parties in the wind energy sector (Pondera, Witteveen+Bos, Quadran, and BITA). However, aside from a two-day site visit to the area, the assessments have been executed through a desk study based on publicly available data and information. The nature and accuracy of the data and information used for the report largely determines the accuracy and uncertainties of the recommendations and outcomes of this report. Furthermore, verification and validation through physical surveys, measurements, design, calculations, and stakeholder consultations are required to determine the definitive techno-economic viability of the wind farm. Therefore, no rights can be derived from any of the presented information and results. For some sites, developers have already initiated follow up studies and therefore might come to different considerations and conclusions based on their acquired data. The use of this wind farm prospectus is limited to informing the Indonesian government, developers, and investors about the indicative potential of the presented location for wind energy development. The authors of this report are not responsible for any consequences that may arise from the improper use of the report.

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