REPORT

Wind Energy Development Prospectus:
92 MW Project in Dairi, North Sumatra

2024

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

ENERGY TRANSITION PARTNERSHIP

Powering Prosperity and Enabling Sustainability in South East Asia

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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 Dairi 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

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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 Dairi Wind Farm, North Sumatra – 92 MW

2.1 Introduction of the wind farm location

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

2.1.1 Geographic location

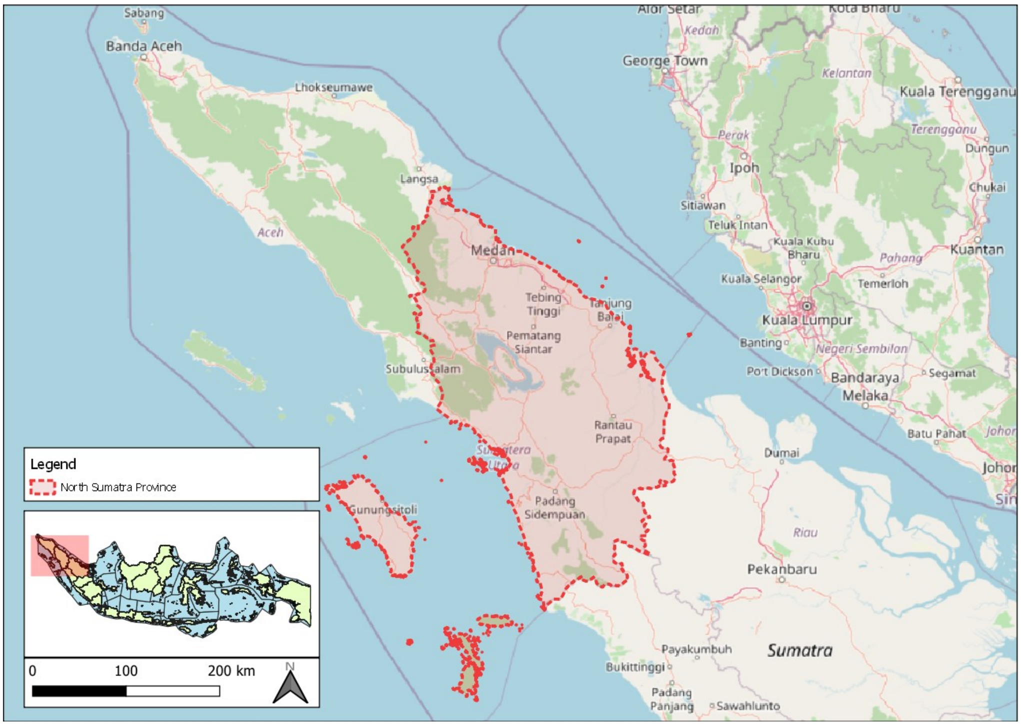

Figure 1. A map of North Sumatra province in which the envisioned Dairi wind farm area is located.

As shown in Figure 1, North Sumatra is a province situated close to northwestern tip of Sumatera Island, which is in the western part of Indonesia. There are three neighboring provinces of North Sumatra, namely, DI Aceh, Riau, and West Sumatra. Covering an area of 72,981 km^2, North Sumatra is inhabited by approximately 15.1 million people in 2022[1], making it the fourth most populous province in Indonesia. GDP per capita of this province is IDR 63.19 million, ranked 14th among all provinces in the country[2]. Furthermore, the province's economic growth is 5.01% in 2023 (c-to-c)[3]. To provide context, Indonesia's economic growth in that year is 5.05% (c-to-c)[4].

[1] https://sumut.bps.go.id/statictable/2023/03/10/2929/jumlah-penduduk-menurut-jenis-kelamin-rasio-jenis-kelamin-dan-kabupaten-kota-jiwa-2022.html
[2] https://www.statista.com/statistics/1423411/indonesia-per-capita-gdp-at-current-prices-of-provinces/
[3] https://sumut.bps.go.id/pressrelease/2024/02/05/1212/ekonomi-sumatera-utara-tahun-2023-tumbuh-sebesar-5-01-persen--c-to-c-.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

North Sumatra is known, among others, for its ecotourism, agriculture, and industry. One of its famous tourist destinations is Lake Toba, an enormous natural crater lake with a large island (i.e. Samosir Island) within its center. Meanwhile, major agricultural products of North Sumatra include coffee, rubber, and palm oil.

There are two industrial estates in North Sumatra[5], namely, Medan Industrial Estate (1,000 ha) and Medan Star Industrial Estate (103 ha). Another industrial estate, Kuala Tanjung Industrial Estate (3,400 ha), is still in development. Strategically located in the Malacca Strait, this estate will be in the vicinity of the Kuala Tanjung Port, which was envisioned to become an international hub for the west part of Indonesia[6]. Goods to be produced on the estate include, among others, palm oil, steel, aluminum, cement, food, and rubber products.

Meanwhile, there is one special economic zone (SEZ) in the province: Sei Mangkei SEZ (2,002 ha)[5]. Located in the southeast of Medan, this SEZ was inaugurated in 2015 to facilitate industrial activities producing international-quality palm oil and rubber[7].

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

1. Sei Mangkei SEZ (23.28 MW by 2025[8])
2. Kuala Tanjung Industrial Estate (18 MVA in 2022)
3. Lake Toba Super Priority Tourism Destination (25.87 MW[9])

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 is located in Dairi Regency, in the northwestern end of Lake Toba.

2.1.2 Status in RUPTL PLN 2021-2030

Figure 2 portrays the electricity system of North Sumatra. The system consists of the main island (150 kV and 275 kV transmission line) and Nias Island (70 kV transmission line). According to RUPTL PLN 2021-2030, the peak load of this province in 2020 is 1,883 MW in 2021-2030. The level of energy production and peak load is projected to increase steadily as shown in Figure 3. This projection is based on the assumption that the average demand growth rate will be 5.5% per year.

[5] https://regionalinvestment.bkpm.go.id/pir/kawasan-industri-kek/
[6] https://northsumatrainvest.id/en/investment-project/kuala-tanjung-industrial-estate
[7] https://www.seimangkeisez.com/en/
[8] https://web.pln.co.id/cms/media/siaran-pers/2022/05/siap-sambut-investor-pln-perkuat-keandalan-kelistrikan-di-kek-sei-mangkei/
[9] https://web.pln.co.id/cms/media/siaran-pers/2022/12/pakai-rec-pln-danau-toba-jadi-destinasi-pariwisata-berbasis-energi-hijau-pertama-di-indonesia/

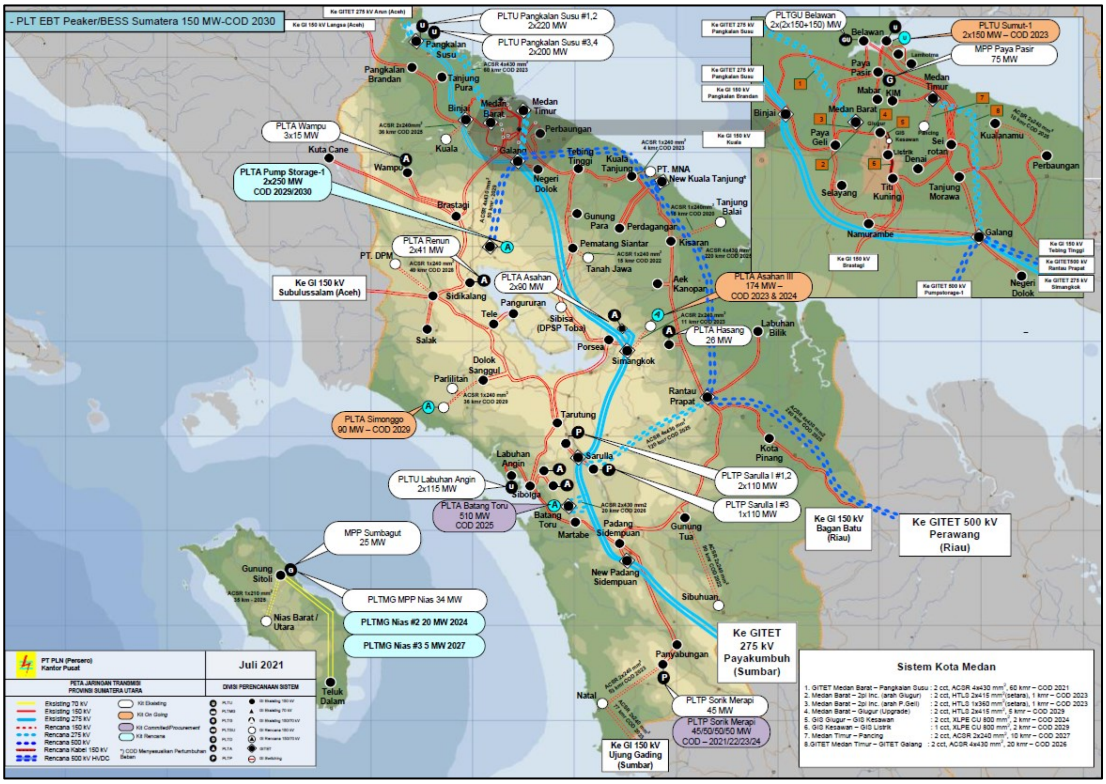

Figure 2. A map of North Sumatra electricity system in RUPTL (Source: RUPTL PLN 2021-2030).

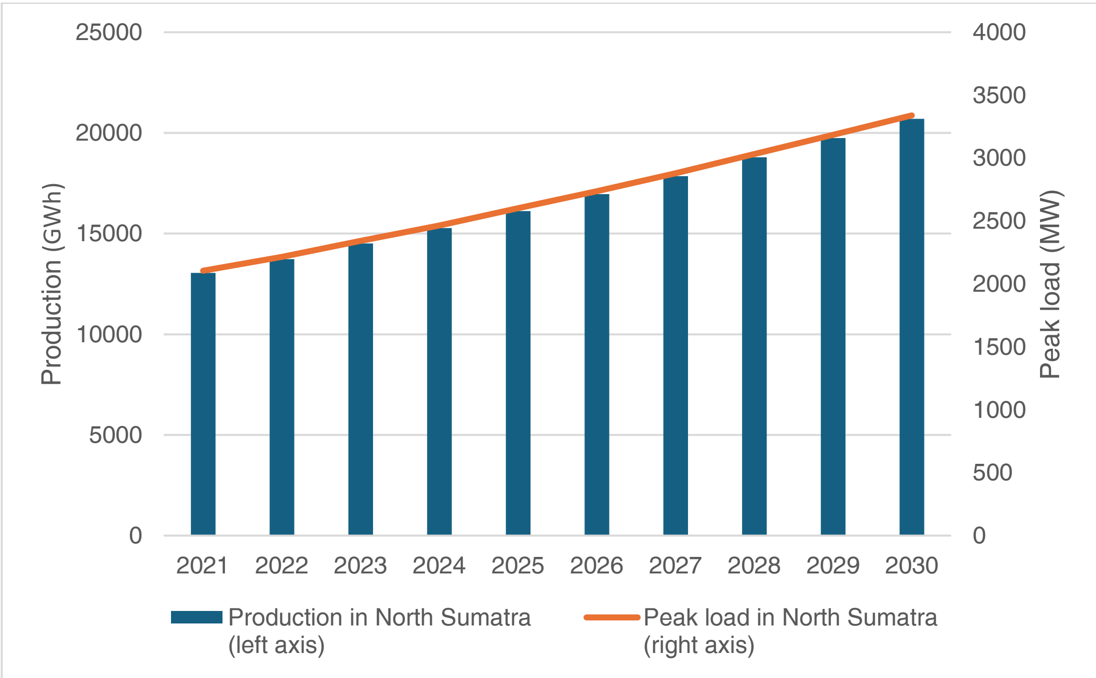

Figure 3. Projected electricity production and peak load in North Sumatra (Source: RUPTL PLN 2021-2030).

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 three sources, namely, PLN, Independent Power Producer (IPP), and *Wilayah Usaha* cooperation. Moreover, wind energy development is only 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 88 MW of wind power potential in North Sumatra.

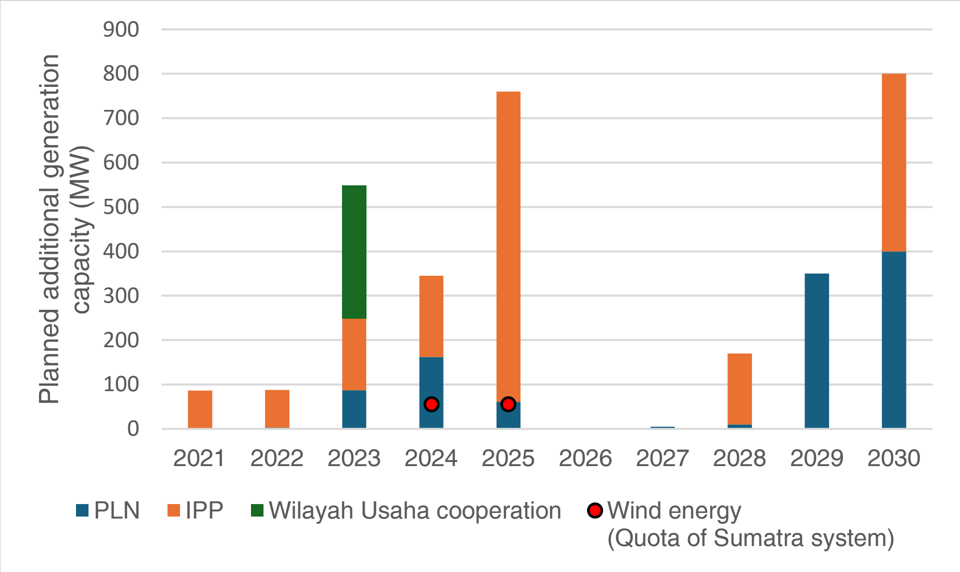

Figure 4. Additional generation capacity being planned for North Sumatra (IPP: Independent Power Producer; Source: RUPTL PLN 2021-2030)

2.1.3 Status of development

To the best of our knowledge, there is no ongoing development for wind energy in North Sumatra. During the trade mission of the Kingdom of the Netherlands to North Sumatra in early 2022, a representative of the Provincial Energy and Mineral Resources Agency mentioned that the wind at the province has relatively unstable speeds with inconsistent direction as per the existing data. Hence, a feasibility study was needed to obtain deeper insights of the wind characteristics and potential.

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 0. 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 Dairi Regency, in the northwestern region of Lake Toba. 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 along a “strip-shaped” area, some of which are scattered at lengthy distances.

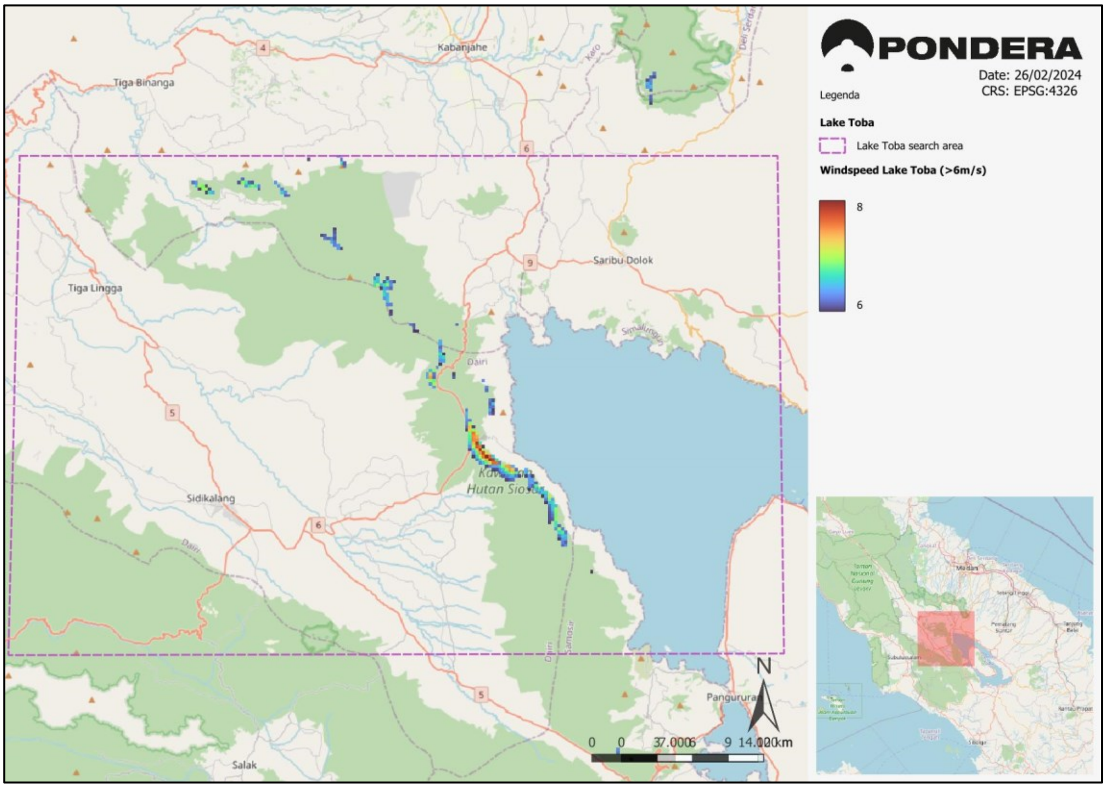

Figure 5. Dairi search area with wind speed distribution. The purple-dash bounding box shows the full search area. The color bar indicates average wind speeds which are above 6 m/s at 100 m height according to the Global Wind Atlas (GWA) climatology.

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.

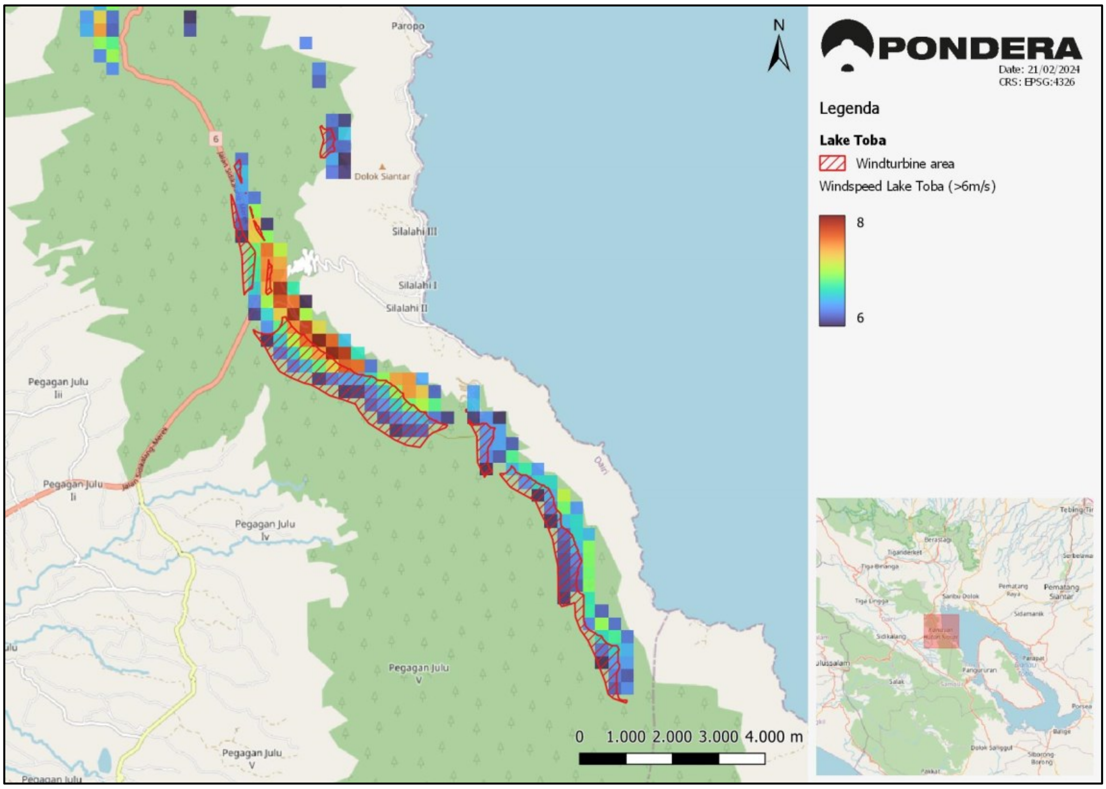

Figure 6. A zoomed-in look at the Dairi search area, focusing in Dairi Regency, along with the wind speed distribution. The red, dashed polygons represent the final WTG-area which meets all the criteria. Average wind speeds above the threshold of 6 m/s at 100 m height according to GWA are shown.

Additionally, Figure 7 visualizes the long-term average wind direction distribution for the Dairi 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 and northeastern winds 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.

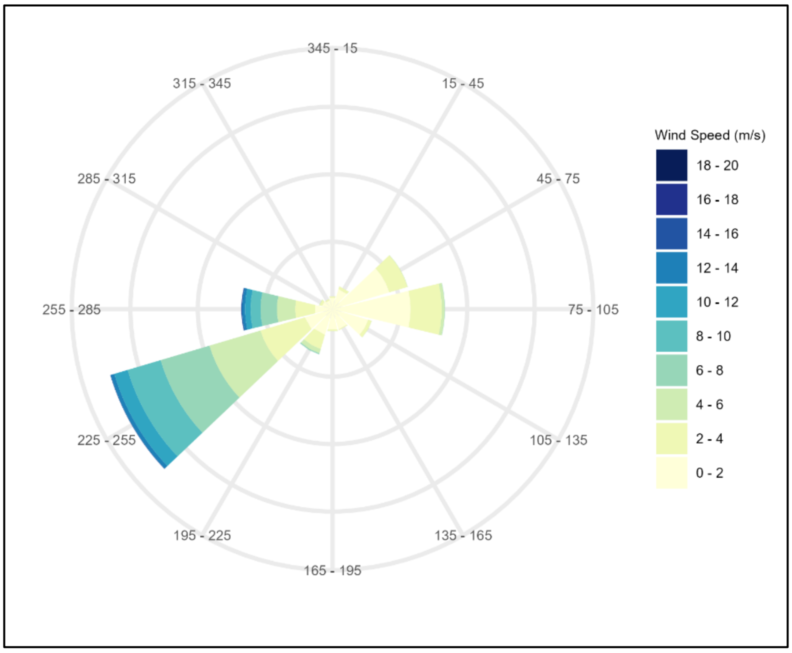

Figure 7. Wind rose diagram with wind directions and wind speed categories based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

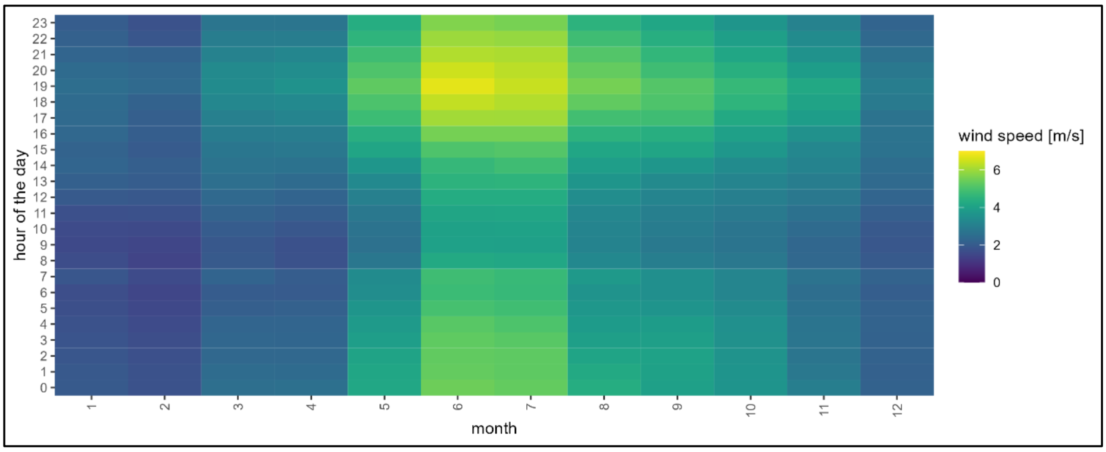

Figure 8. The wind speed distribution throughout the day, visualized per month of the year. Based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

2.2.3 Topography

Figure 9 shows the topography of the search area in the Dairi 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.

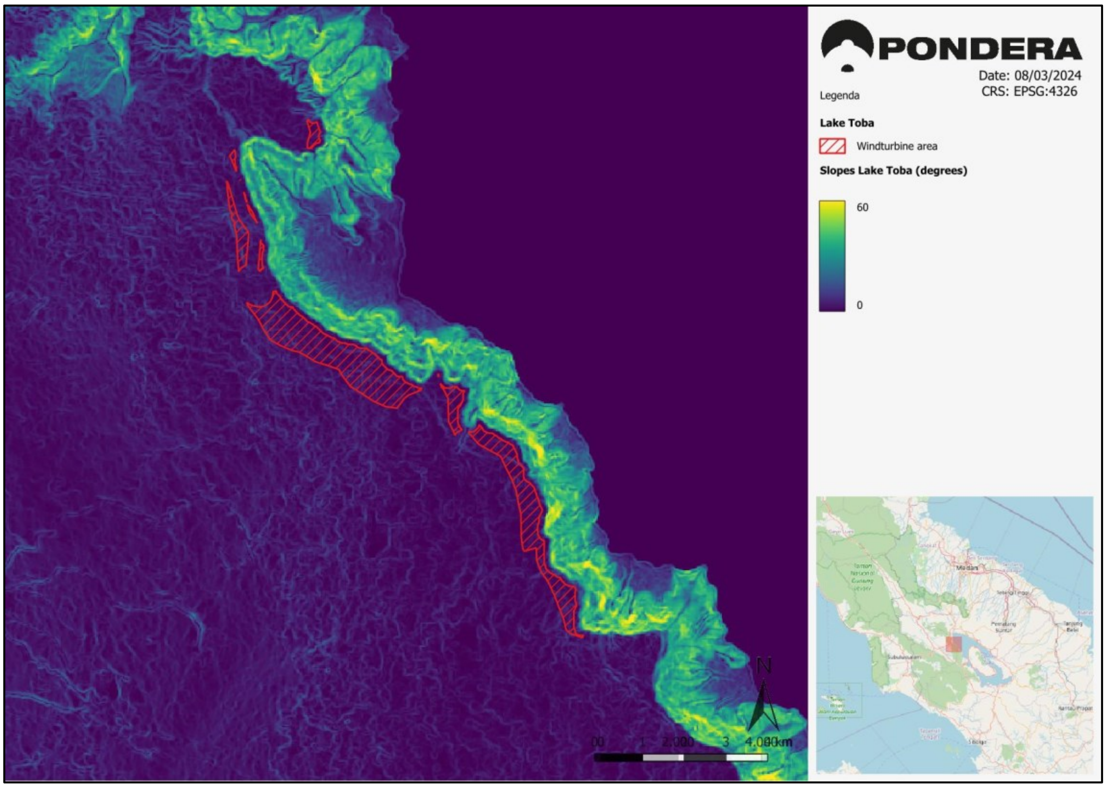

Figure 9. Topography of the Dairi WTG-area, showing the slope (in degrees; according to calculated based on FABDEM data) at the region.

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.

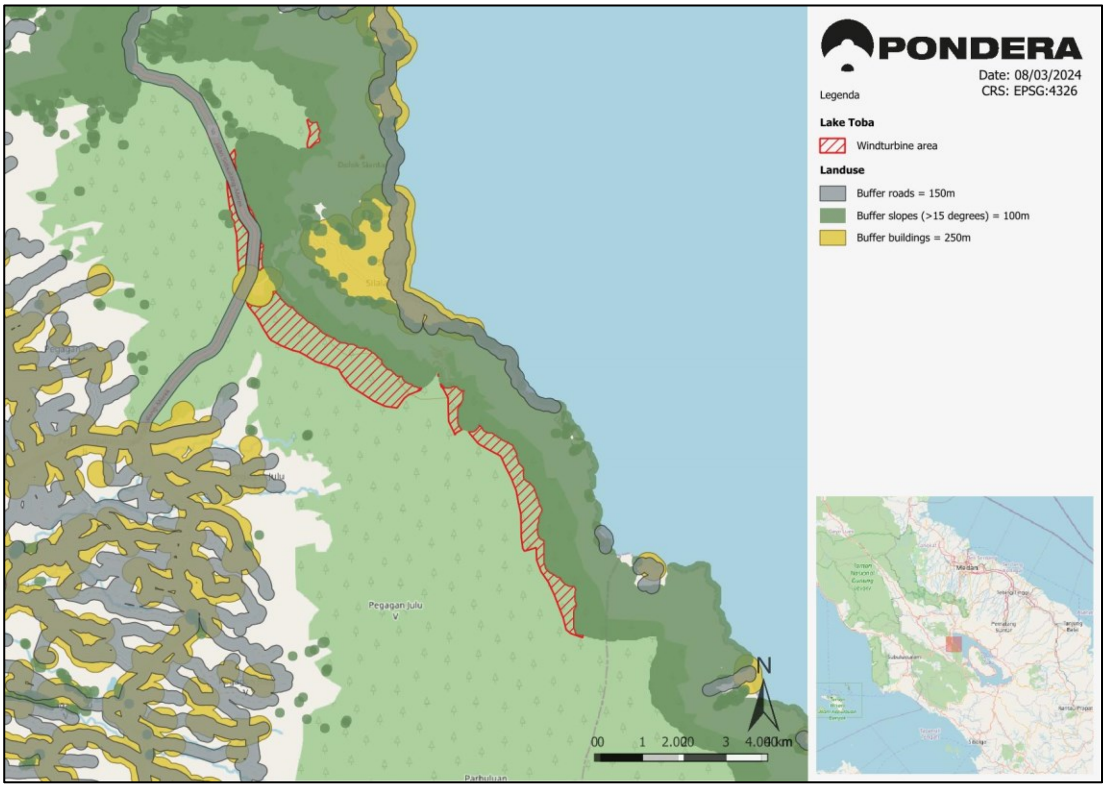

Figure 10. Exclusion zones at the Dairi area based on land use, topography, and residential areas. Source: calculation based on FABDEM elevation, ESRI, and OSM.

2.2.5 Specific permitting requirements

According to the Dairi Regency Spatial Plan (*Rencana Tata Ruang Wilayah* or RTRW) 2014-2034, the continuous area with promising wind speed is located in the Protected Forest Area (*Kawasan Hutan Lindung*). Figure 11 shows the overlay between the spatial plan and the final WTG-area. According to Government Regulation 23/2021, a Forest Area Utilization Permit (*Izin Pinjam Pakai Kawasan Hutan* or IPPKH), or what is now known as Forest Area Use Approval (*Persetujuan Penggunaan Kawasan Hutan or* PPKH) is needed to develop a wind farm at the area. This permit is issued by the Ministry of Environment and Forestry (MoEF), and thus, the future wind farm developer must apply for this permit.

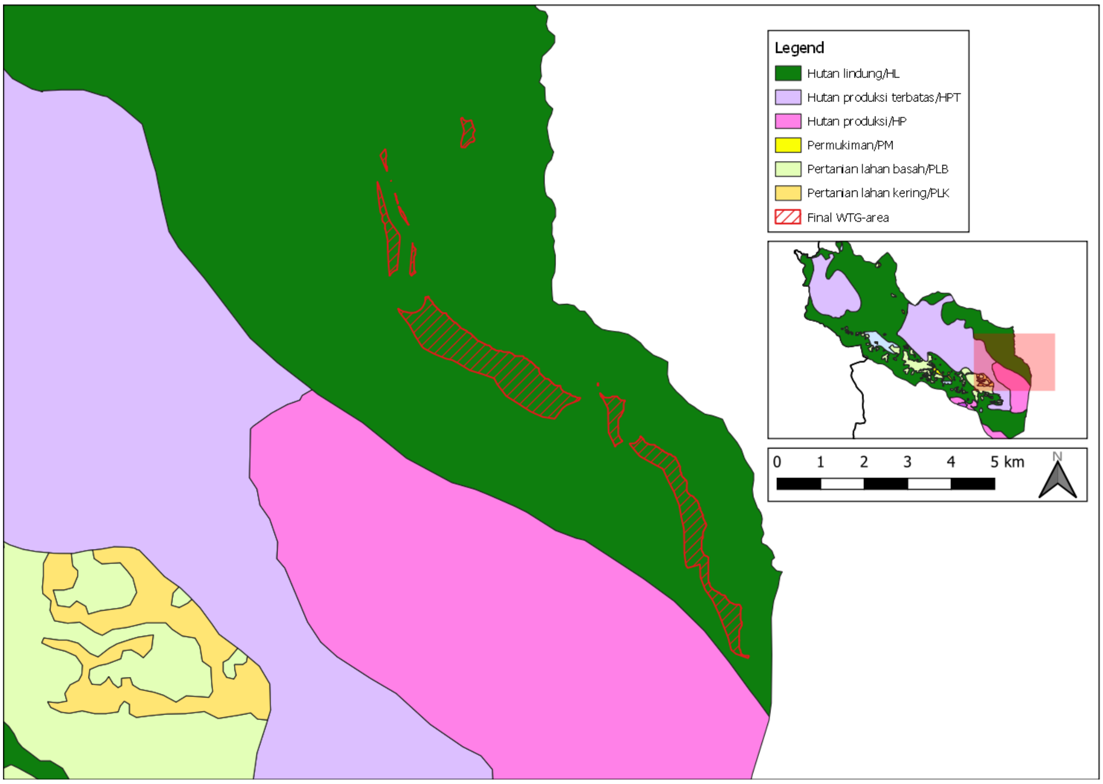

Figure 11. The map of spatial plan of Dairi Regency (RTRW 2014-2034) overlaid with the final WTG-area.

Regulation of the Minister of Environment and Forestry 7/2021 stipulates the conditions to obtain the permit for activities in the electricity sector. Depending on the amount of forest area in the province, the permit owner may eventually be obliged to, among others, pay a compensation non-tax state income, pay non-tax state income for utilizing the forest area, and rehabilitation planting at river basin with a ratio of at least 1:1. These costs have been taken into account in the business calculation made in Section 2.9.

It is important to note that the obtained RTRW of Dairi Regency is for the year 2014-2034. It is not yet known whether a new Regional Regulation has been issued regarding the new RTRW, or if the new RTRW is still being revised/prepared. Hence, confirmation from the competent agency in Dairi Regency is required. If there is already a new RTRW Regional Regulation, the RTRW used in this report is no longer valid. Nevertheless, if the RTRW of Dairi Regency has not yet been revised or is still being revised, then this RTRW is still valid.

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.

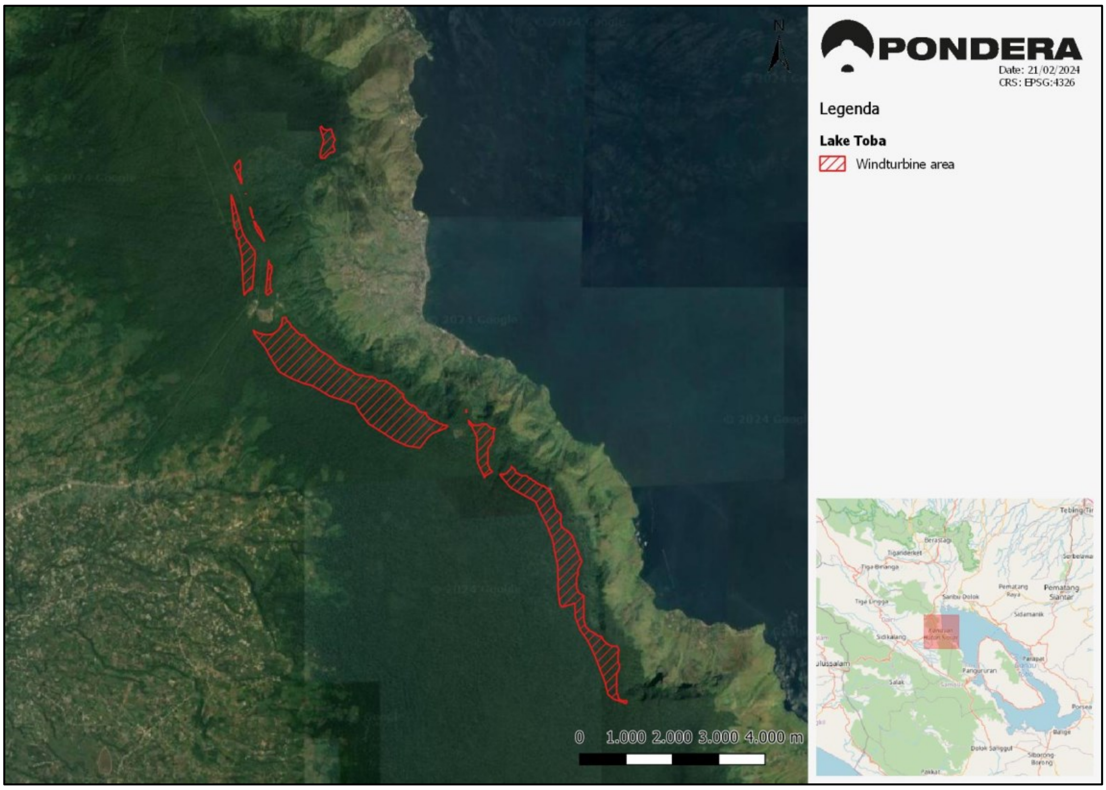

Figure 12. Final WTG-area based on the restriction criteria. Source: Google Satellite Images.

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.

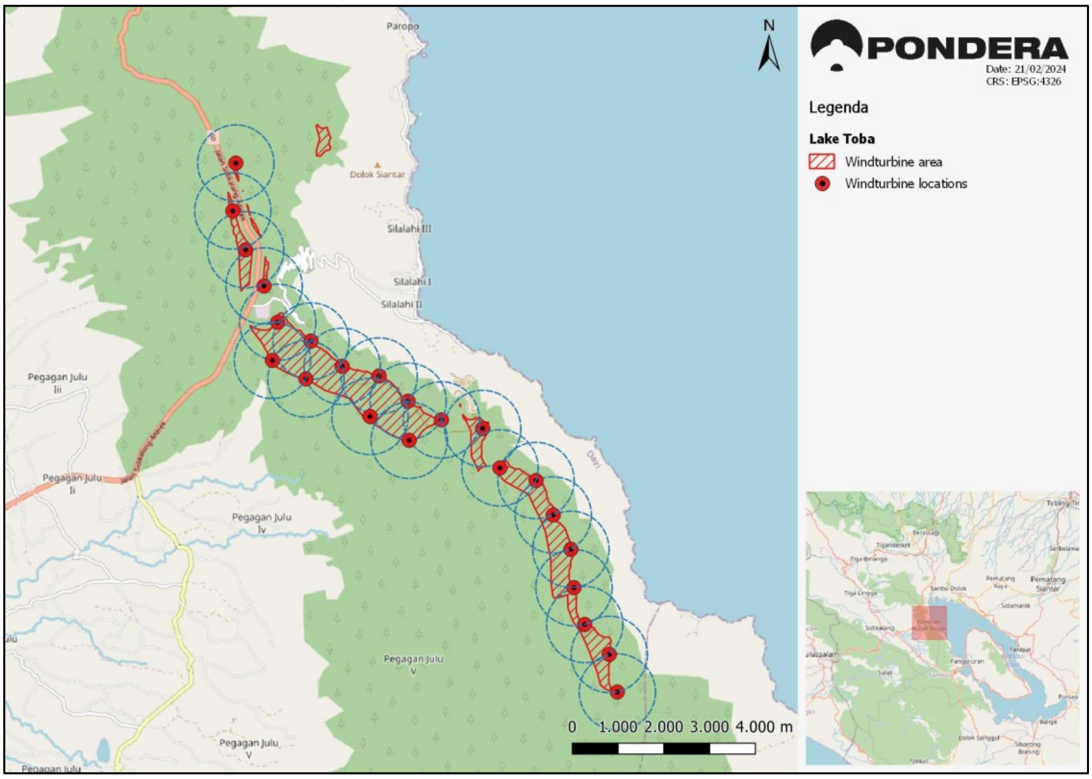

Figure 13. Preliminary wind farm layout at the final WTG-area.

Figure 13 displays an overview of the wind turbine locations in the final WTG-area. A total of 23 wind turbines were positioned into the area, amounting to an envisioned total installed capacity of 92 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.

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.

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.

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.

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 port of the envisioned Dairi wind farm is Port of Belawan, which is located in Medan at a distance of ~140 km from the site. This is a major port with quay cranes serving northern Sumatra (see Figure 15). There are no smaller ports available closer to the site.

Figure 15. A satellite image of the Port of Belawan in Medan.

The port consists of multiple parts. The outer-most part (shown on the left in the image above) seems to be most suitable for large ships. The port is connected to the ring road of Medan by a highway. The ring road itself is a highway on the northern and eastern side. Transport could take place over the western- (shorter, but no highway) or eastern side.

The first ~50 km from the port to the site are relatively flat, after which the road ascends to the plateau surrounding Dairi. The road leads from sea level to an elevation of a maximum of 1,800 m (see Figure 16 and Figure 17). The steepest sections average a slope of about 5%.

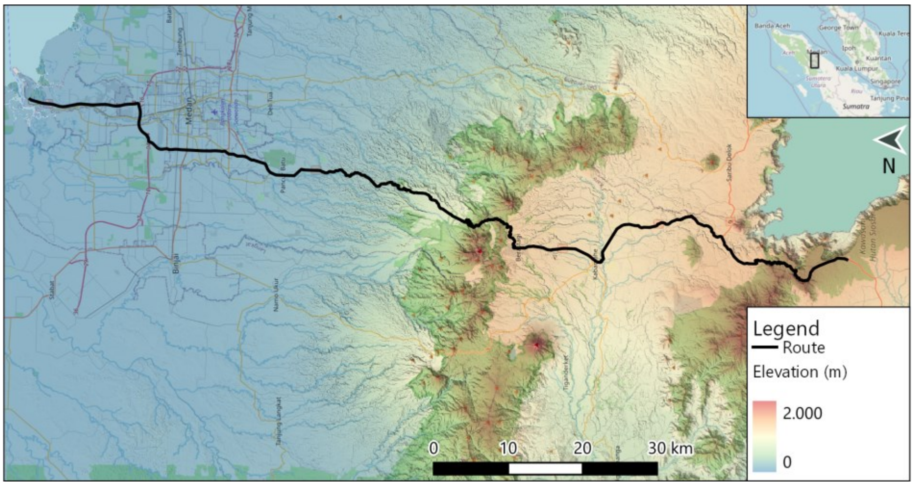

Figure 16. Route from Medan (A) to access point of the site (B)

In the following figure, the road profile is presented for the route shown above.

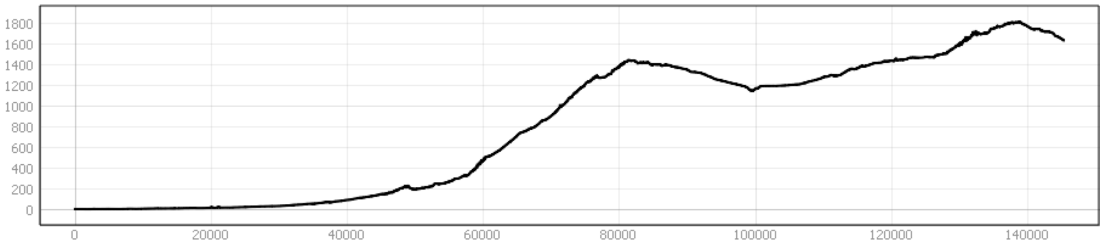

Figure 17. Road profile Medan (A) to site (B)

The route is mostly ascending, in two sections hairpins are used to climb the steep terrain. The first section with hairpins is situated near Sibolangit village. One hairpin is particularly narrow (see Figure 18) and will need redesign before wind turbine transport can take place. A complicating factor is that a water extraction site is located directly next to the road, managed by PDAM (the main water provider in Indonesia). The presence of this well might be the reason this is the only hairpin turn that has not been widened on the entire stretch of the route.

Figure 18. The only hairpin on the route that has not been widened.

In the central part of the route (near Bandar Baru, 58-60 km in Figure 19), a section with 11 hairpins has recently been widened. According to locals, these works were completed around 2021. It is expected that because of this operation no redesign is needed, and the current layout is sufficient for the wind turbine transport.

At the end of this section, a lot of (private) water wells are present next to the road. Numerous water trucks drive up and down from Medan to these locations to fill their trucks and meet the water demand of the city. During wind turbine transport it may be that roads cannot be closed for extended periods without influencing the local water supply.

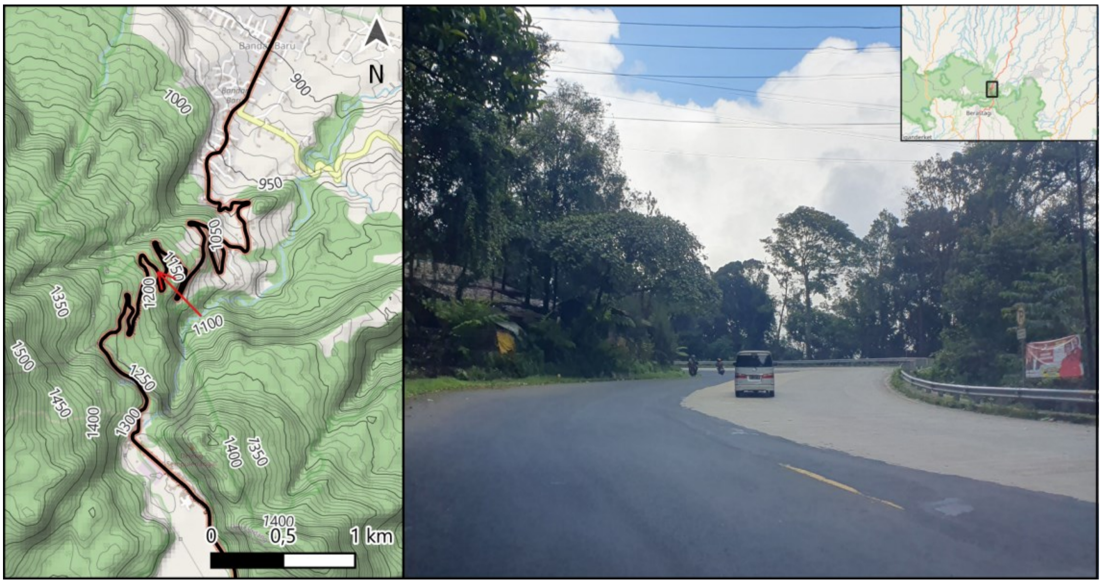

Figure 19. Section with hairpins south of Bandar Baru. In the sharp turns the road has been widened significantly.

About 15 kilometers before the site (south of the town Merek) there is another section with hairpins and sharp turns (see Figure 20 and Figure 21). A part of the road leading into the mountains has been upgraded in 2022 and of good quality. However, a short section (2.3 km) is still in bad shape, narrow, and has not been widened. It is expected that this part will need upgrading before the transport of wind turbines can take place. The steepness of this section averages at 4.8% (194 m gain over 4,003 m) and should not be a limiting factor when using this road.

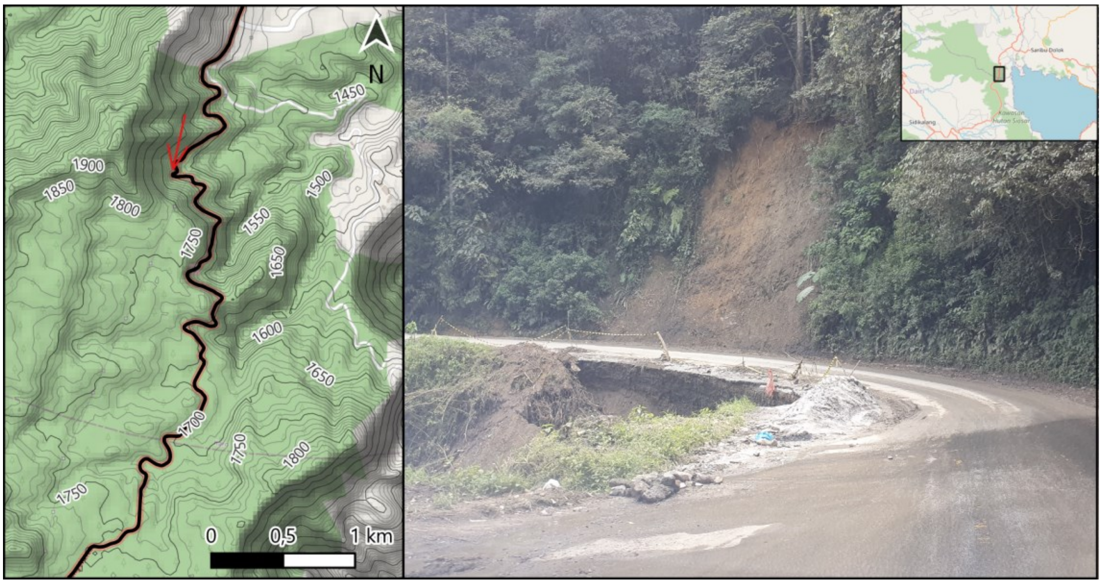

Figure 20. Section with sharp turns south of Merek. The road is in bad condition, and several recent landslides were observed.

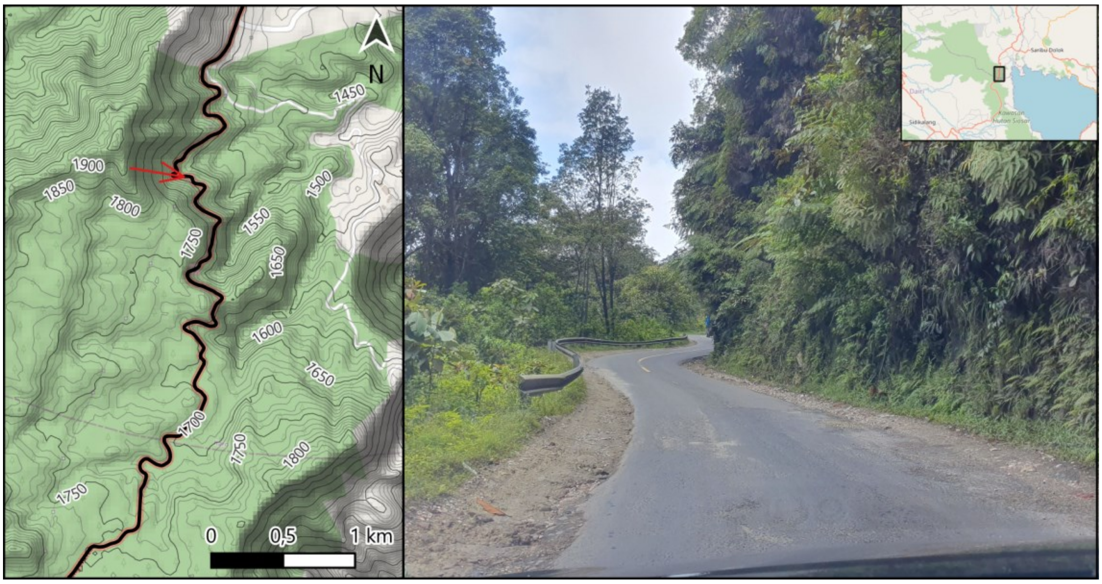

Figure 21. Section with sharp turns south of Merek. The road is in worse condition than other areas and features a steep slope on one side of the road.

A complicating factor is that this road is built on steep slopes with a near vertical wall on one side. This limits the number of degrees the turbine blades can rotate during transport. During the site visit (which took place in the wet season) about 10 recent landslides were observed on this section alone, which gives an idea how prone to landslide these slopes are (see Figure 20).

While this section is also part of the Medan-Sidikalang national road, no online information has been found if plans for widening are already present. This section is the only part of the Medan-Sidikalang national road that is in bad shape, as the road from Medan to the north and the road south to Sidikalang have already been widened.

On the route from Medan to the site, some bridges are present (see Figure 22). Most are larger bridges which feature steel beams on the sides and top, limiting the amount of maneuvering space during turbine transport. Smaller bridges are made from concrete and seem to be in good condition. Within the site itself no streams or rivers are present. During the site visit no ‘red flags’ have been seen regarding these bridges. It is expected that no bridges will need to be built for heavy transport. However, all bridges need to be inspected before heavy transport takes place.

Figure 22. An example of a steel bridge (left) and a concrete bridge (right)

2.4.3 Transport within the site

The main north-south road (Medan-Sidikalang national road; see Figure 23) leads through the first part of the wind site. Outside of this road only two other roads are present in the area; one road leading down to Lake Toba (Paropo village) and one service road (of presumably PLN; see Figure 23) perpendicular to the crater rim. The service road is made of concrete and leads from the hydropower complex to the surge tank halfway down the slope to the lake. This service road gives access to about half of the wind farm location in this region, over a distance of 5 km. Reusing this road will reduce road construction costs significantly, while also minimizing the ecological impact on the surrounding forest.

Figure 23. Medan-Sidikalang main road (left) and service road of PLN within the site area (right).

No other roads are present, thus for all other potential turbines locations new access roads will have to be constructed as can be seen in Figure 24. As the topography within the site is fairly flat and well accessible, this should not be a major obstacle from a construction perspective.

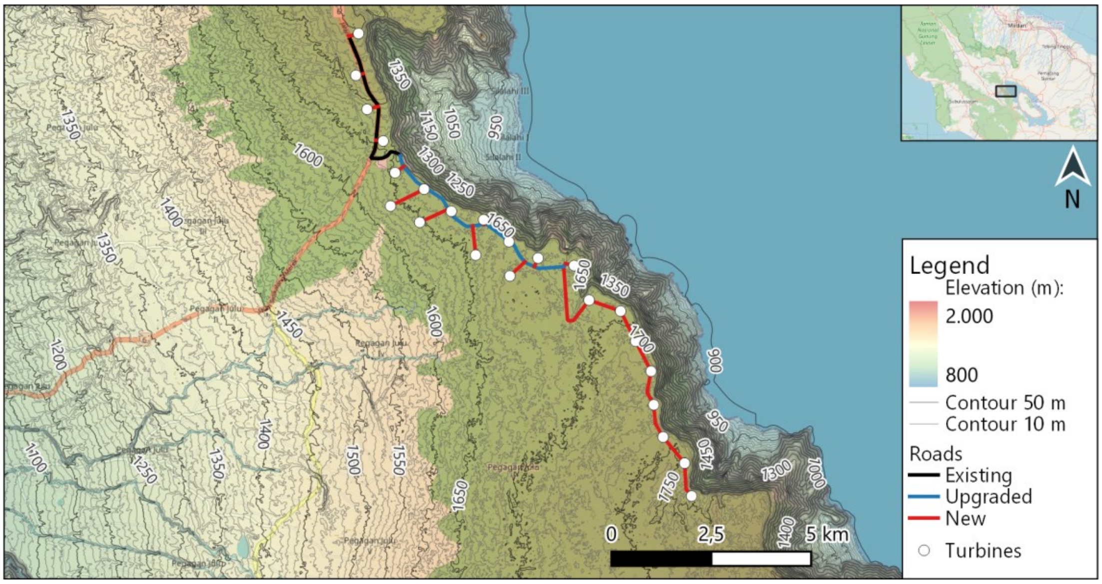

Figure 24. Preliminary road layout

For the feasibility study, we recommend looking into the following points regarding wind turbine transport:

- Inquire if there are plans in place for road improvement on the road south of Merek, as all the other sections of this road have recently been upgraded. It may well be that this section will be upgraded as well, and investment into improvement might not be necessary; and
- Improvement of the hairpin south of Sibolangit may have to be done in corporation with PDAM, as there is a water extraction site close to the road.

2.5 Geology and seismicity conditions

The terrain in the area is dominated by the presence of the Toba Caldera, an elongated volcano crater with a size of 100 x 30 km. At the site, the elevation of the crater rim is approximately 1,700 m above sea level. The crater wall, one continuous slope, leads down to Lake Toba with a water level of 905 m.

Within the site, the variation in topography is minimal. The terrain gently slopes towards the west, away from the caldera (collapsed volcano crater). The soil consists of volcanic ash (tephra), no rock outcrops have been observed during the site visit and is also not expected based on the geological history of the site. For the road alignment within the site, no special attention is necessary to circumnavigate steep slopes and/or places with hard rock.

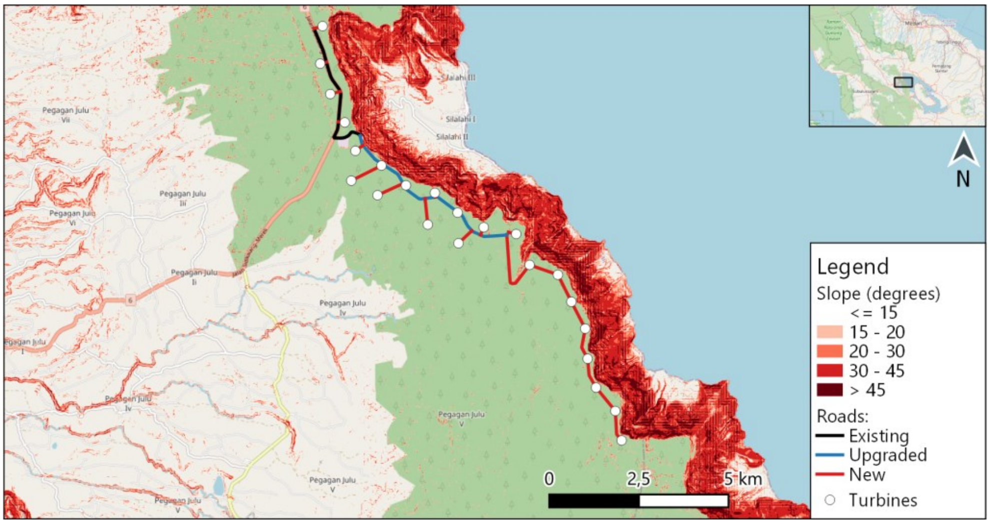

Figure 25. Slope conditions with road alignment. All roads and platforms can be built in relatively flat terrain (<15 degrees).

From a terrain perspective, the topography within the wind farm is suitable for wind farm development as all roads and platforms can be built on flat terrain (see Figure 25). However, this flat terrain borders the caldera edge. As the wind turbines are built close to this edge, special attention should be paid to the stability of the soil. The minimum safe distance between the turbines and caldera edge should be investigated further during the feasibility stage.

The next subsections will describe specifically the area's geology and seismicity in greater depth.

2.5.1 Geology

The soil consists of welded Ignimbrite (deposits of pyroclastic flows) (Chesner, 2012). This is a very fine deposit of ash-like material with some larger rocks in between, mostly up to a few cm in size. During the site visit it was determined that these deposits could easily be separated/crushed by hand, and should be seen as a sediment and not as solid rock (see Figure 26).

Figure 26. Outcrop next to the service road. Sediment is excavated by a crane for road construction. Width of outcrop in picture is ~3 m.

This geology combined with the topography makes the slope of the caldera vulnerable to land movement. 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 land movement vulnerability index of the soil in and around the WTG-areas.

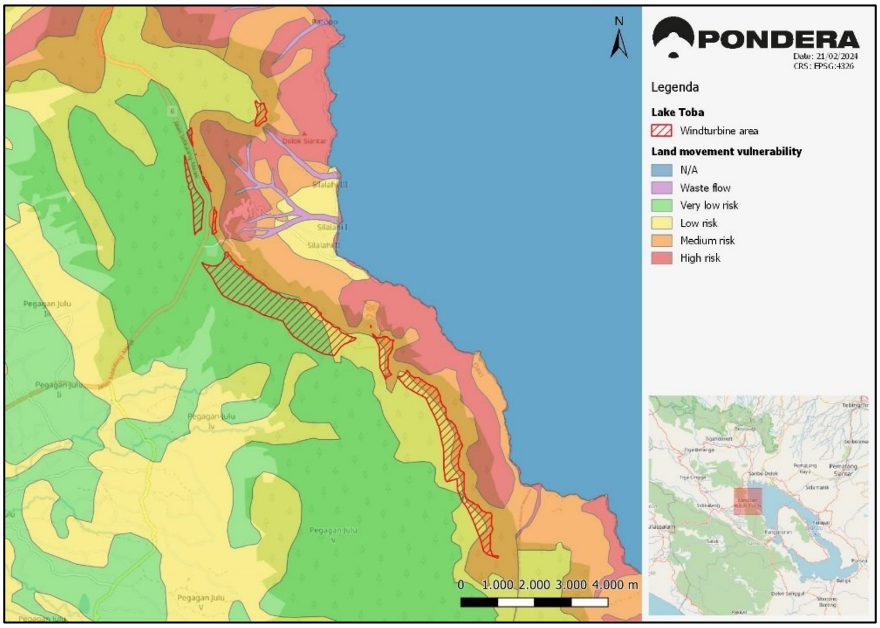

Figure 27. Land movement vulnerability index for Dairi.

The stability and capability of the soil to carry wind turbines closer to the caldera edge (where higher wind speeds are expected) should be further investigated during the feasibility stage. This can be done by a geotechnical soil investigation (determining soil characteristics such as shear strength, density, permeability, etc.), and a following soil stability analysis.

2.5.2 Seismicity

The site lies relatively close to the Great Sumatran Fault (see Figure 28). This is a collection of dextral faults running over the entire length of the island with a total length of ~1,900 km. The fault accommodates the movement between the oblique plate convergence between the Indo-Australian oceanic plate and overriding Sumatran-Eurasian continental plate. The slip rate (movement between the plates) is estimated to be 14-15 mm/year. This movement is not constant, but happens intermittently during earthquakes. On average, a major earthquake occurs once along the 1900 km long fault system every 5 years (Natawidjaja, 2018).

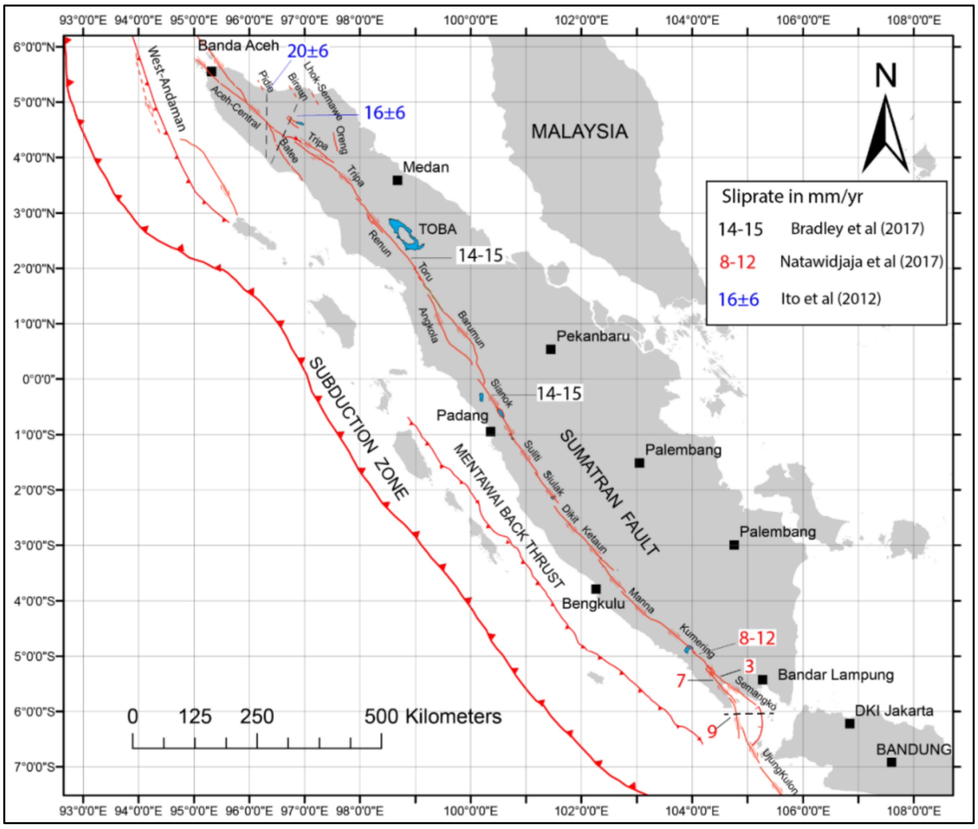

Figure 28. Generalized location of Great Sumatran Fault system, running along the entire length of the island.

According to the Ministry of Energy and Mineral Resources (MEMR or *Kementerian ESDM*), large portions of the area have the potential to be hit by strong earthquakes with an intensity larger than VIII on the Modified Mercalli Intensity (MMI) scale. Figure 29 provides a visual representation of the earthquake risk level in and around the WTG-area.

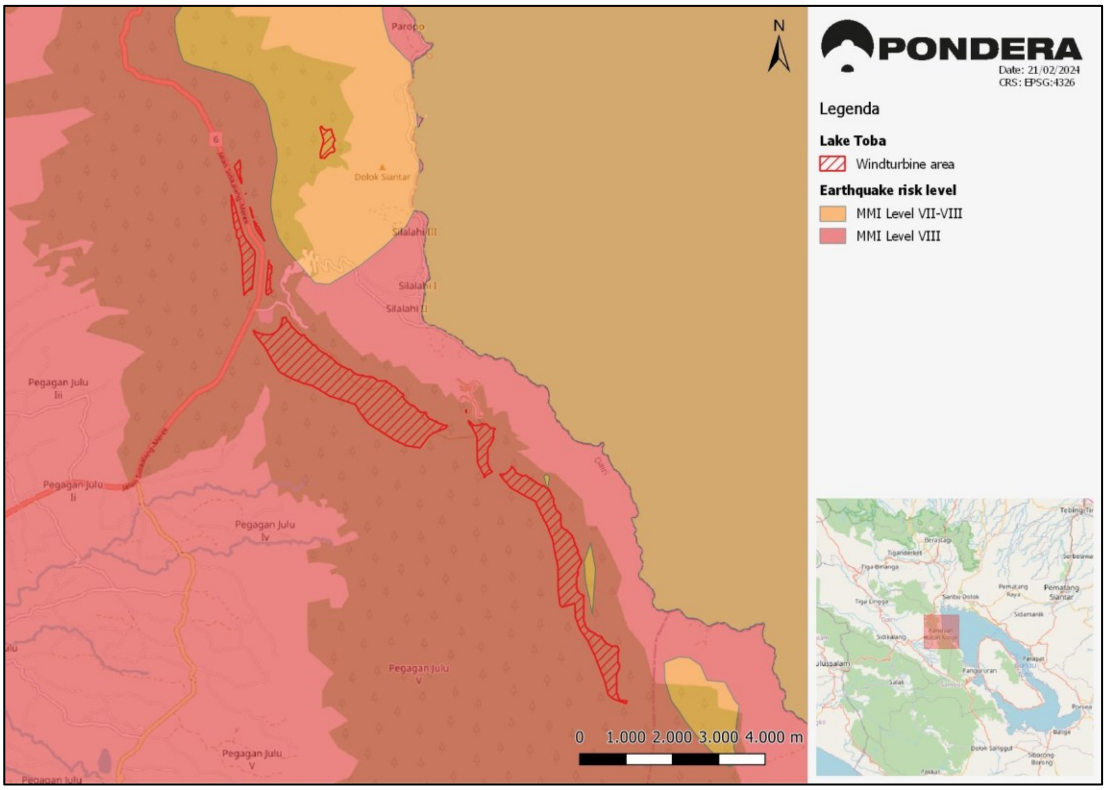

Figure 29. Earthquake hazard and risk level at Dairi

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

Most of the envisioned wind farm area (>90%) is covered by primary forest (see Figure 30) and is part of a larger elongated forested area with a length of about 60 kilometers. Because of the elevation and temperature, the height of the trees is limited to about 15 m.

Within the site, the forest has been cut into several separate sections by the roads, buildings and power lines (see Figure 31). Near the main road, within the site area, a part of a hydroelectric power plant of PLN is present (Figure 32). This is a complex that is part of the PLTA Lau Renun hydroelectric power plant, with two turbines and a total capacity of 41 MW each. The turbines (which are present at the lake) are powered by water streaming down under gravity from surrounding rivers into Lake Toba.

Apart from the main roads one road in parallel with the caldera edge leads to a surge tank (part of the hydropower complex) halfway down from the caldera to the lake. The entrance of this gravel road is blocked with rocks. Power lines intersect the site which connects the power station to the existing electrical grid. Underneath the power lines, the forest has been cleared (see Figure 31).

Figure 30, Figure 31, and Figure 32 show a general impression of the site nearby the caldera.

Figure 30. Impression of the site. Edge of the caldera with dense forest. A small service road of the hydroelectric power plant leads through it, which can be seen in this photo as an opening in the canopy.

Figure 31. Heavily forested caldera edge. In the center the road to Medan, on the far right and left some power lines are visible. Forest below the power lines has been cut down.

Figure 32. A complex of PLTA Lau Renun, part of the hydroelectric power plant. The turbines themselves are situated at the lake.

2.6.2 Biodiversity and environmental impact

As most of the site is covered by primary forest, it is expected that this is a high biodiversity area (see Table 1). The full area of the site lies within a protected forest (*Hutan Lindung*) of the Dairi Regency. Development in the forested area will likely have an impact on biodiversity and the environment. 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)

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

Due to the presence of the hydroelectric powerplant, habitat fragmentation has already taken place in large parts of the site. Only in the southeastern part of the site, no fragmentation of the forest has taken place yet. New road construction in this area, and along the existing access road of PLN will open up the area more. Without proper mitigation this might lead to further (illegal) clearing of forest and development.

Observed flora and fauna:

According to the online biodiversity database of Global Biodiversity Information Facility (GBIF), several animal and plant species were observed in the area (see Figure 33) that are categorized in 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[10]. 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). In the following tables, the observed flora and fauna that are categorized as at least 'near threatened' are listed.

Table 1. List of observed fauna (source: GBIF) which are at least near threatened according to the IUCN global red list category

Animals	English Name	Status
Symphalangus syndactylus	Siamang (gibbon)	Endangered (EN)
Macaca fascicularis	Con Song Long-tailed Macaque	Endangered (EN)
Acridotheres javanicus	Javan Myna	Vulnerable (VU)
Buceros bicornis	Great Hornbill	Vulnerable (VU)
Pycnonotus bimaculatus	Orange-spotted Bulbul	Near threatened (NT)

[10] https://www.britannica.com/topic/IUCN-Red-List-of-Threatened-Species

Animals	English Name	Status
Lophura inornata	Salvadori's Pheasant	Near threatened (NT)
Psilopogon mystacophanos	Red-throated Barbet	Near threatened (NT)
Prinia familiaris	Bar-winged Prinia	Near threatened (NT)

Table 2. List of observed flora (source: GBIF) which are at least near threatened according to the IUCN global red list category

Plants	English Name	Status
Nepenthes rigidifolia		Critically Endangered (CR)
Paphiopedilum tonsum	-	Endangered (EN)
Nepenthes spectabilis	-	Vulnerable (VU)
Nepenthes mikei	-	Vulnerable (VU)
Nepenthes rhombicaulis	-	Vulnerable (VU)

Figure 33. The area in which the abovementioned flora and fauna has been observed (covering the envisioned wind farm location)

According to the spatial plan of Dairi Regency (RTRW 2014-2034) as stipulated in the Regional Regulation of Dairi Regency 7/2014, some development is still allowed within the protected area. The following are the most important conditions:

Protected forest area zoning regulations as intended in Article 74 paragraph (1) letter a is stipulated as follows:

a. *The use of protected forests zone is carried out with the following provisions:*
    1. *does not reduce, change or eliminate its main function;*
    2. *limited land cultivation;*
    3. *does not cause negative impacts on biophysical and social- economic aspect;*
    4. *do not use mechanical equipment and heavy equipment; and*
    5. *do not build facilities and infrastructure that change the natural landscape.*

b. *Mining activities in protected forest areas are still permitted as long as they are not carried out openly, provided that the former mining area must be reclaimed so that it can function as a protected area again.*

However, when permission from the government is granted international funding is also a point of attention. 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.

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 x 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 carried out during the feasibility phase.

2.6.3 Social impact

Apart from a few houses on and near the power plant complex, the area within and directly around the wind farm is inhabited by humans (see Figure 34). The potential turbines are placed at a distance of at least 300 meters from the few houses that are present. The buildings that are present house the PLN workers and some families that run the shops and restaurant at the intersection. In the east of the wind farm lies Paropo village, which mainly consist of fishermen, small shop owners, and small scale farmers. A few hotels and homestays are present to accommodate (mainly local) tourists.

The social impact is therefore more or less limited to the visual presence of the turbines near the caldera rim, and impact of road closures during transport. When turbines are placed near the rim, they will be visible from large distances, which may have an impact on how the site is seen from a touristic standpoint.

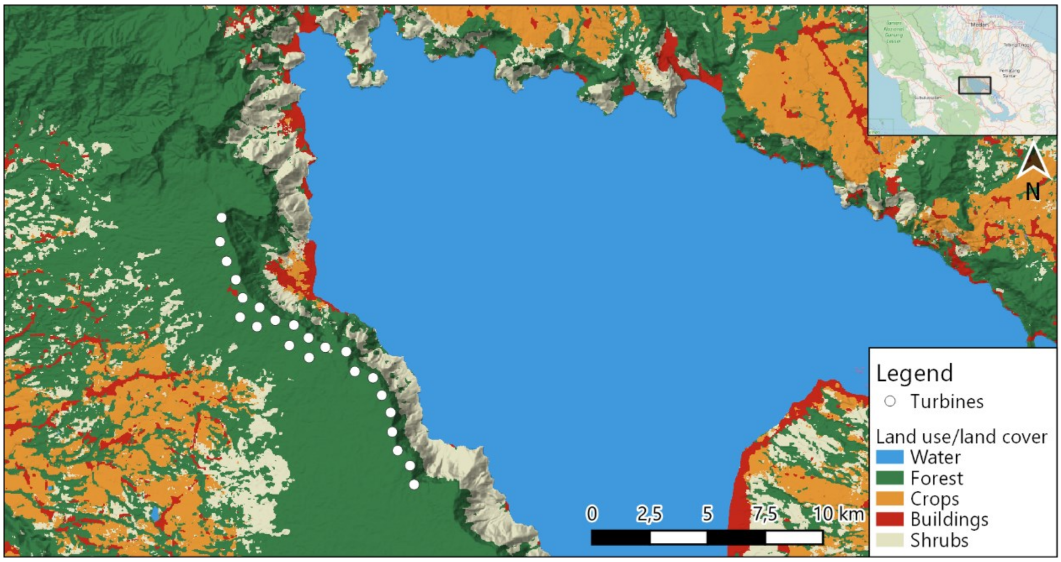

Figure 34. Land use map based on satellite imagery (ESRI/Sentinel 2, 2022). The area directly around the wind farm is primarily covered by forest and shrubs. Comparing the data to actual satellite imagery, some barren cropland between Paropo village and the turbines are recognized as buildings.

The special geological features of the Toba caldera and resulting topography make the area branded as a national and international tourist destination. The area is recognized as a Geopark by UNESCO. In Indonesia, 10 Geoparks are present (e.g. Raja Ampat, Mount Ijen, Mount Rinjani). Inside the caldera, many hotels and resorts can be found. Wind turbines located on the rim (where wind is abundant) will therefore be also potentially visible from a long distance. This may lead to local resistance from the hospitality industry. However, the Toba caldera is large (30 x 100 km), and wind turbines will not be visible from all sides of the caldera or Samosir Island.

According to online information from geoparktoolkit.org, the goal of Geoparks is to *'stimulate economic activity within the framework of sustainable development. (…) All Geoparks therefore have a remit, with UNESCO's assistance, to foster socio-economic development that is culturally and environmentally sustainable.'* With the right approach, it is expected that a wind farm could fit within the abovementioned framework. Placing the turbines away from the rim may make them invisible from the base of the caldera rim near Paropo village (see Figure 34), but not from larger distances such as the opposing side of the caldera or from parts of Samosir Island. However, due to the high humidity in these tropical regions, the opposing side of the caldera is often barely visible during late morning and afternoon.

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

Population

The population in Dairi Regency slightly increased from 311,665 people in 2021 to 324,747 people in 2023. However, the population growth fluctuated from 1.3% in 2021 to 1.83% in 2023. The graph is shown in Figure 35.

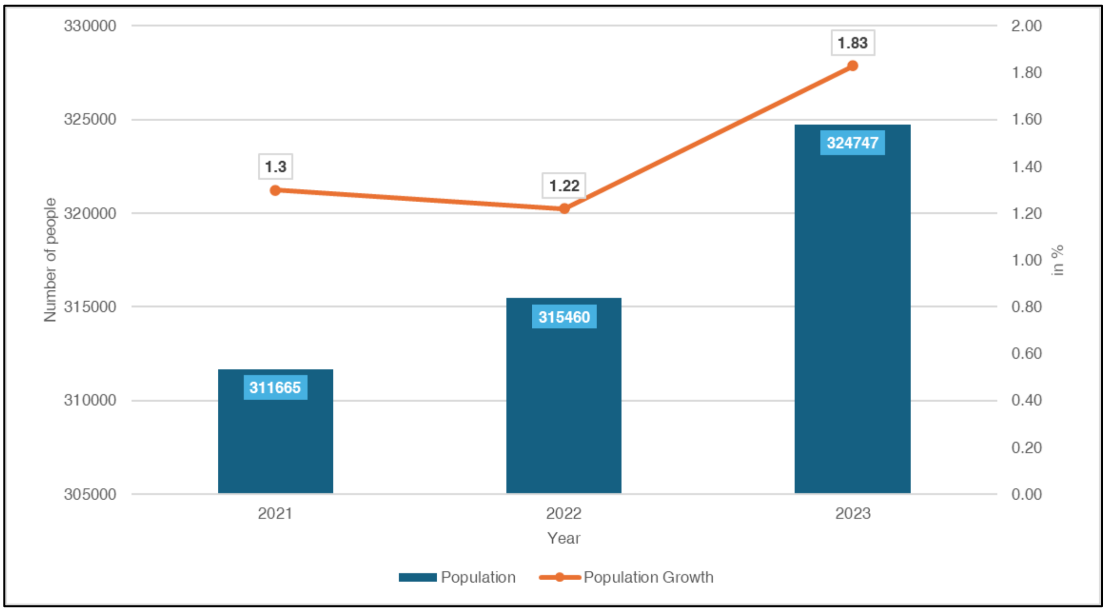

Figure 35. Population and annual population growth in Dairi Regency from 2021 to 2023 (Source: [Statistics of Dairi Regency (bps.go.id)]).

The population pyramid of Dairi Regency in 2018 is shown in Figure 36. The total male and female population from age 0 to 75+ years old were almost equal. Meanwhile, the gender ratio in the regency was 1.004 in 2022.

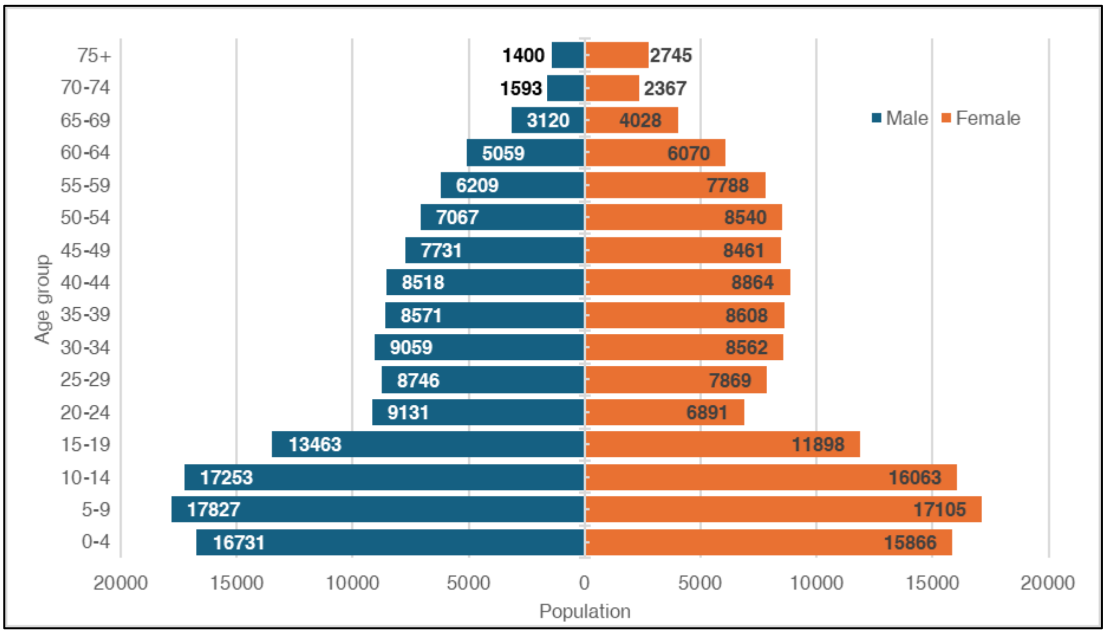

Figure 36. Population pyramid in Dairi Regency in 2018 (Source: [Statistics of Dairi Regency (bps.go.id)]).

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. Both of these employment data are displayed in Table 3. The TPAK in Dairi in 2023 was 84.81%, declined from the previous year. The unemployment rate (TPT) in the same year was 1.23%, increased from the previous year.

Table 3. Labor force participation rate and unemployment rate in Dairi Regency in 2021-2023 (Source: BPS Kabupaten Dairi).

Metric (in %)	Year		
	2021	2022	2023
Labor force participation	85.73	85.01	84.81
Unemployment rate	1.49	0.88	1.23

The number of workers according to highest education from in 2023 is presented in Table 4. Overall, the workforce was dominated by graduates of high school. The second largest group is the graduates of middle school, followed by primary school.

Table 4. Workers according to highest education (people) in Dairi Regency from 2023 (Source: BPS Kabupaten Dairi).

Educational attainment	Working	Unemployed	Total of Economically Active	Percentage of Working to Economically Active (%)
Primary school (SD)	36,793	528	37,321	98.59
Middle school (SMP)	47,689	148	47,837	99.69
High school (SMA)	61,893	1,522	63,415	97.60
Vocational high school (SMK)	25,446	-	25,446	100
Diploma I/II/III	6,146	-	6,146	100
University	16,993	237	17,230	98.62
Total	**194,960**	**2,435**	**197,395**	**98.77**

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. The corresponding rates in the regency in 2022-2023 is presented in Table 5.

Table 5. Pure participation rate in Dairi Regency in 2022-2023 (Source: Statistics of Dairi Regency (bps.go.id)).

Pure participation rate	Year	
Educational level	2022	2023
Primary school	93.78	99.28
Middle school	87.70	77.47
High school	90.19	71.73
University	23.97	11.70

The number of educational facilities in Dairi Regency is shown in Table 6. In 2023-2024, there are 261 units of primary school 12 units of Islamic primary schools. Furthermore, there are 63 units of middle school and 3 units of Islamic middle schools. The number of high schools, vocational high schools, and Islamic high schools are respectively 24, 16, and 3 units.

Table 6. Educational facilities in Dairi Regency in 2023-2024 (Source: Badan Pusat Statistik, 2024).

Type of School	State	Private	Total
Primary school	245	16	**261**
Madrasah Ibtidaiyah (Islamic Primary School)	4	8	**12**
Middle School	37	26	**63**
Madrasah Tsanawiyah (Islamic Middle School)	1	2	**3**
High School	13	11	**24**
Vocational High School	6	10	**16**
Madrasah Aliyah (Islamic High School)	1	2	**3**

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).

The Human Development Index in Dairi Regency from 2021 to 2023 had an increment from 71.84 to 75.18, as shown in Table 7.

Table 7. Human Development Index, Gender Empowerment Index, and Gender Development Index in Dairi Regency in 2021-2023 (Source: Statistics of Dairi Regency (bps.go.id)).

Metric	Year		
	2021	2022	2023
Human Development Index	71.84	72.56	75.18
Gender Empowerment Index	61.11	62.57	62.34
Gender Development Index	98.05	98.15	98.44

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 increase, as shown in Table 7.

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 7.

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 Sidikalang 150 kV PLN substation (ULTG) is selected for this, located in the east of the village of Sidikalang. The aerial photo of this substation is included in Figure 37. 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 37. Location of the Sidikalang 150 kV PLN substation (ULTG). Source: Google Maps.

2.7.2 Schematic design transmission and distribution network

In Figure 38, the schematic design of the transmission and distribution network is illustrated. The 23 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 6 wind turbines, the generated electricity is distributed to one of the four 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 Sidikalang substation.

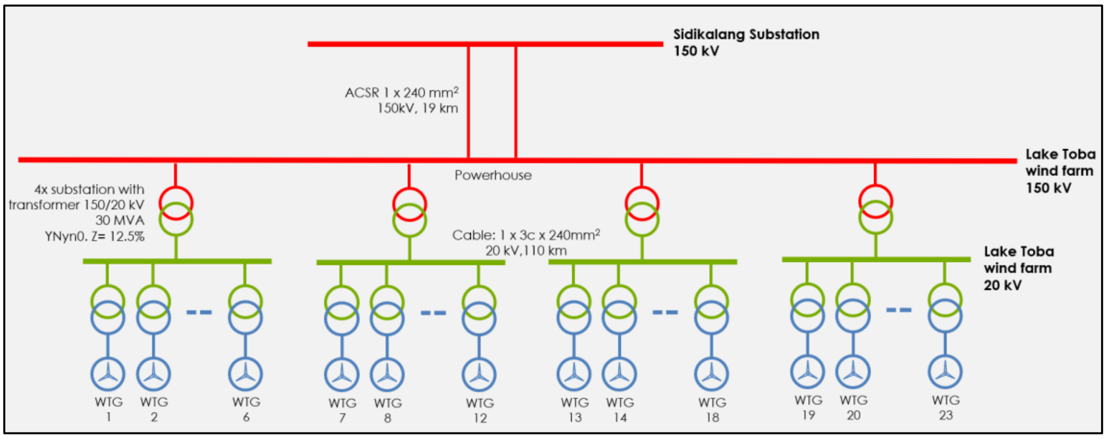

Figure 38. A schematic design of the transmission and distribution network at the envisioned Dairi wind farm.

The overhead transmission line between the powerhouse and the PLN substation is assumed to be a straight line between both locations, covering 19 km as visualized in Figure 39. A total of 48 towers are planned with an intermediating distance between the towers of 340-450 m.

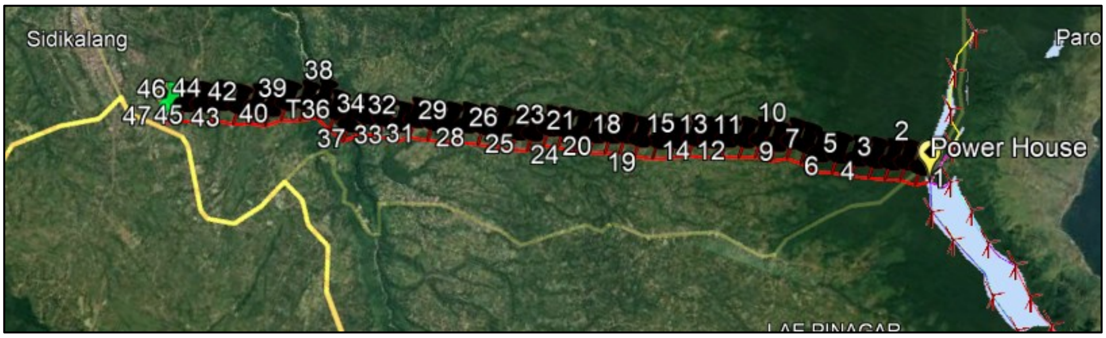

Figure 39. A schematic representation of the position of overhead transmission line between the powerhouse and the Sidikalang substation.

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 Dairi 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 placed in (very) complex terrain with high turbulence intensity.

The horizontal resolution of the LES is 100 m and the resolution in vertical direction is 40 m. The climatology is based on a selection of 50 representative days selected between the years 2002 and 2024. The selection was made based on the wind speed data of the nearest ERA5 grid point at 100 m height and accounts for variations in the wind climate due to El Niño and La Niña.

Figure 40 shows the resulting climatology at the locations of the WTGs. The modeled long-term wind speed, which is averaged over all 23 WTGs at the planned hub height of 140 m, is 9.0 m/s. It must be noted that the mean wind speed in the Global Wind Atlas (GWA), is notably lower (7.6 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 trends in wind speed are consistent between the long-term data and the Global Wind Atlas: WTGs closer to the ridge have the highest wind speeds (up to 9.9 m/s). In the southeastern part of the area, the lowest wind speeds are found (7.2 m/s). 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.

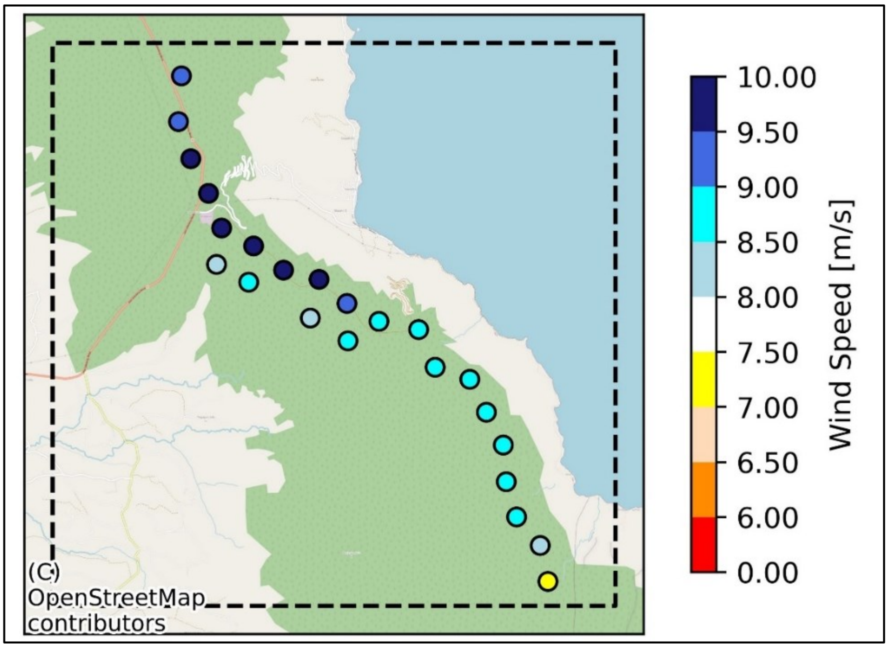

Figure 40. Long-term average wind speed results with the ASPIRE model at a height of 140 m at the turbine locations. The black-bordered circles represent the wind turbines, whereas the colors within the circles indicate the respective long-term average wind speed.

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 8 presents the estimated losses on the wind farm level.

Table 8. Expected losses on the wind farm level.

Category	Types of energy loss	Amount	Explanation
Interaction	Wake losses [%]	2.0%	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 2.0%.
	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 Forsting (2016)[11] with linear parametrization is used to calculate blockage. 0% blockage is expected for the layout at Dairi.
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.

[11] 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
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.
	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.

Category	Types of energy loss	Amount	Explanation
	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 wind turbines are positioned in a forest and changes in tree height or tree felling might lead to different roughness and changes in wind speed. However, due to a limited tree height (of approximately 15 m), and no substantial tree felling 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 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 [%]		**14.8%**	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 9.

Table 9. Energy yield for all 23 WTGs at the Dairi wind farm.

Parameter [Unit]	Amount
Number of new WTGs	23
Rated Power per WTG [MW]	4.0
Total rated Power [MW]	92.0
Rotor diameter [m]	~170
Hub height [m]	140
Air density [kg/m³]	0.986
Wind speed [m/s]	9.0
Gross result [MWh/yr]	507,848
Gross results including wake effects [MWh/yr]	497,691
P50 [MWh/yr] [12]	**432,897**
P90 (25 yr) [MWh/yr]	**321,941**
P50 [hrs/yr]	4,705
P90 (25 yr) [hrs/yr]	3,499

2.8.3 Power output variation

In Subsection 2.8.2, we have provided an estimate of the P50 annual production, equal to 432,897 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.

[12] Note that the P50 value is based on the LES calculation with a mean wind speed of 9.0 m/s, while the Global Wind Atlas predicts wind speeds in the order of 7.6 m/s. 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 41 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. This graphic illustration is relevant to take into account for a grid impact study in subsequent studies for this project location.

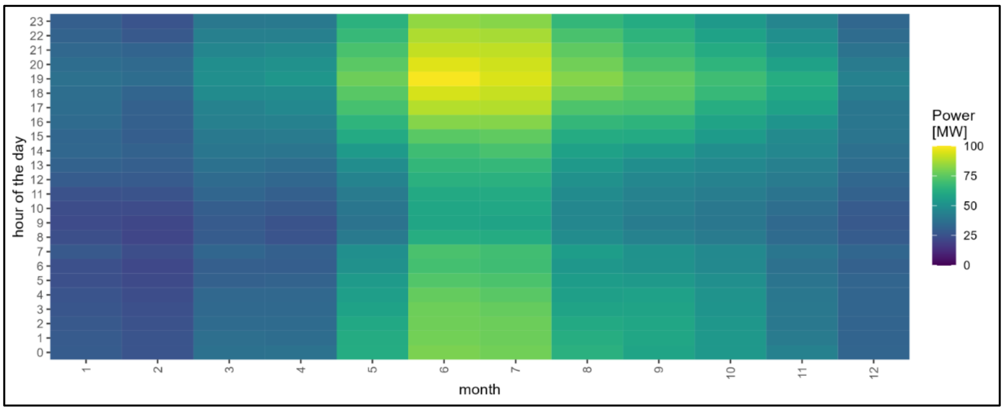

Figure 41. Overview of the monthly variation of wind farm average power output per hour of the day based on the P50 values from Subsection 2.8.2 in combination with the monthly and hourly variation in wind speed from EMD-WRF.

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 (2 met masts + 1 LiDAR, for 2 years)
- 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 23 wind turbines at the wind farm are shown in Table 10.

Table 10. Wind turbine quantities relevant for the envisioned Dairi wind farm.

Main component	Quantity
Nacelle incl. generator (4 MW)	23 pcs
Blade (85 m)	69 pcs
Tower segments (total 140 m height)	138 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 Belawan (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[13];
- The cost includes transport, crane rental, installation, and commissioning.

[13] 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 23 wind turbines at the wind farm are shown in Table 11.

Table 11. 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	13 km
	Upgrading existing road (service road PLN)	5.5 km
	Upgrading existing road (transport route Medan to site) a hairpin near Sibolangit village and a section south of Merek.	2.5 km
Strengthening bridges (incl. design, materials, transport, labor)	Concrete bridge strengthening	4 bridges
	Steel bridge strengthening	2 bridges
Foundations (incl. design, materials, transport, labor)	Anchors (72 per foundation)	1,656 pcs
	Anchor cages	23 pcs
	Concrete (230 m^3 per foundation)	5,290 m^3
	Steel (35 tons per foundation)	805 tons
Crane hardstands (incl. design, materials, transport, labor)	Crane hardstands (50 x 100 m) using gravel	23 hardstands

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

- Civil works are including design, materials, transport, and labor;
- Strengthening of highway bridges are excluded (5 bridges on toll road around Medan and to the port). It is assumed that these are strong enough;
- 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 12.

Table 12. A list of assumptions on the electrical works components.

Main component	Sub-component	Quantity
Transmission line (19 km, 48 towers)	Transmission towers	48 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	23 pcs
	LV switchgear	1 pc
	DC Supplies	1 pc
	Lightning protection	1 pc
	Transformers 20 kV (5 MVA)	23 pcs
	2x3C 300 mm cable	567 m
Wind farm electrical works (between the powerhouse, substations, and wind turbines)	Switchgear	23 pcs
	MVAC Cable (1 x 3c x 240) 50 and 300 meters	111 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 (four for the entire wind farm)	Transformer 150/20 kV 30 MVA	4 pcs
	Neutral Grounding Resistor	4 pcs
	Switchyard	1 pc
	In/outgoing bays, coupler, busbars, Panel RCP	4 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, assuming IDR 2 million /ha/year
- Insurances (e.g. machine breakdown insurance, third party liability)

2.9.2 Cost assumptions

In Table 13, 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 a 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[14]) and to the other 7 locations.

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

Table 13. Cost assumptions per cost component.

Cost component	Baseline cost including VAT	Comment	Cost range
Preparation works	USD 2,240,000	DEVEX: Prior to Financial Close	90% - baseline -120%
Project management	USD 6,225,000	DEVEX: Until CoD	Baseline
Wind turbines	USD 64,108,000	CAPEX: Including transport and installation	90% - baseline -120%
Civil works: foundations	USD 9,216,000	CAPEX	80% - baseline -150%
Civil works: roads	USD 8,363,000	CAPEX	80% - baseline -150%
Civil works: crane hardstands	USD 1,265,000	CAPEX	80% - baseline -150%
Electrical works	USD 30,369,000	CAPEX	90% - baseline -120%
Land acquisition	USD 9,549,000	CAPEX	90% - baseline -150%
Risk contingencies	USD 10,009,000	DEVEX + CAPEX	Baseline
Lower bound total investment cost (DEVEX + CAPEX)	**USD 126,978,000**	**Investment cost per MW: USD 1,380,000**	
Baseline total investment cost (DEVEX + CAPEX)	**USD 141,373,000**	**Investment cost per MW: USD 1,537,000**	
Upper bound total investment cost (DEVEX + CAPEX)	**USD 174,913,000**	**Investment cost per MW: USD 1,901,000**	
Baseline operational expenditure (OPEX)	**USD 2,759,000 / year**	**Operational cost per MW / year: USD 30,000**	

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 North Sumatra) = 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 14. Results of 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	28.75%	25.40%	19.62%
Average Debt Service Coverage Ratio (DSCR) at P90	1.69	1.53	1.27
Net profit at P50 over 25 years	USD 373,619,000	USD 356,350,000	USD 316,159,000

3 Conclusion and Recommendations

Based on the conducted analyses and available data, it is concluded that the overall techno-economic viability of a wind farm near Lake Toba in Dairi Regency could be promising. The average wind speed of 9.0 m/s (although with high uncertainty to be minimized in further studies) is a significant contributor to the potentially promising business case. That, in combination with the wind turbines available at a competitive price level, easily accessible terrain, and reasonable distance to the existing PLN grid, could result in a favorable business case (from a project developer's perspective) and potentially a good technical feasibility. However, the envisioned wind farm entails risks that should be considered 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. It is therefore recommended that wind measurements are conducted in the area. We recommend placing met mast at least on two locations and a LiDAR at one location at this site for at least two years (to cover seasonal variation of the wind speed; see Figure 42). The background of the figure is the wind speed from the Global Wind Atlas (GWA). 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. With a blue diamond, the location of an additional LiDAR measurement site is indicated.

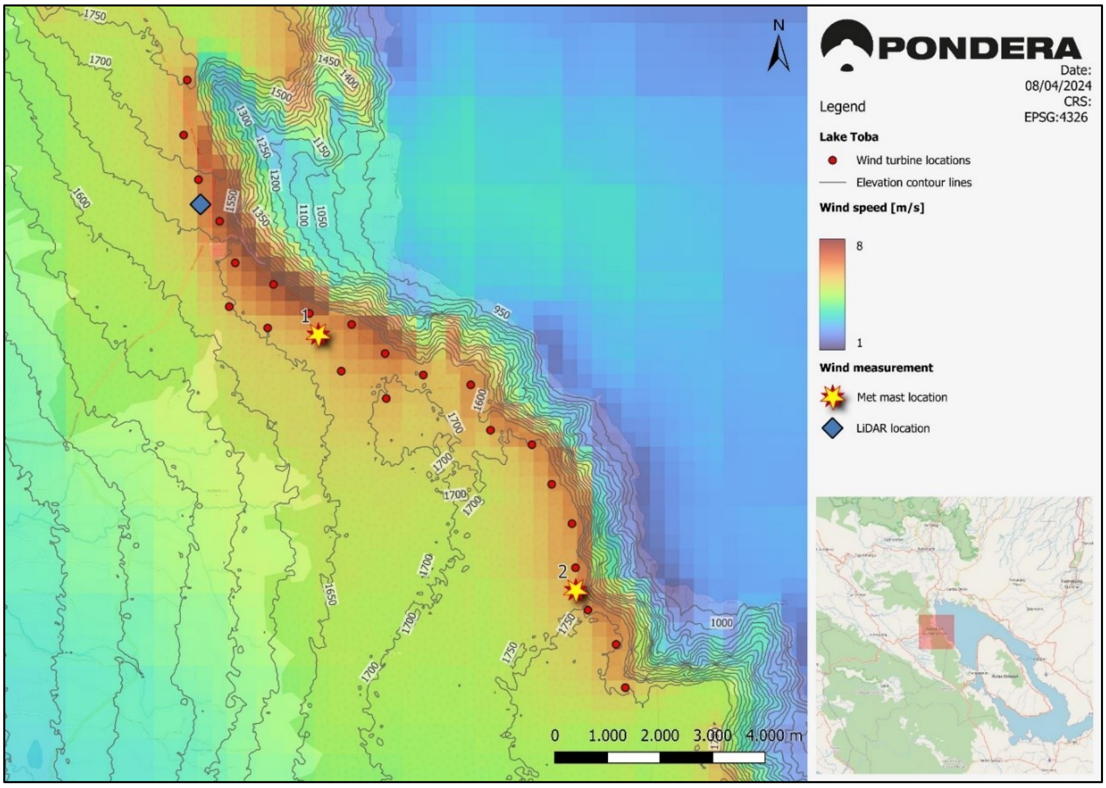

Figure 42. Recommended met mast and LIDAR locations.

One mast should be positioned in the more central part of the site and one in the southern area so that the measurements cover the entirety of the windspeed variation in the area. Additionally, it is recommended to deploy the LiDAR in the northern area at a later stage for acquiring additional wind data and lowering the uncertainties.

Due to the large height variations at Lake Toba, the wind turbines could experience up- and downdrafts. This is why a met mast near the steep caldera ridge is preferred. It is our recommendation to specifically install an ultrasonic 3D anemometer in the mast, which not only measures the horizontal velocity but also the vertical velocity of wind. In the northern part of the site, the height variations are less prominent, and the wind turbines are further from the ridge. Here a concurrent temporal LiDAR measurement could be considered to define the wind speed gradient over the area.

- **Land use and permitting:** As can be derived Figure 34 and Subsection 2.2.5, the wind farm is planned in a Protected Forest Area, and therefore it is necessary to obtain specific approvals and permits from the authorities. Considering these required actions, it is also important for the developer to assess the land use / ownership in greater detail early 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 the Port of Medan is the most suitable starting point for the transport over land. To ensure that the port in Medan 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. Furthermore, an alignment with the local authorities is required about the future improvement of the road south of Merek. For the improvement of the hairpin in the south of Sibolangit, an alignment with PDAM is required since there is a water extraction site close to the road. Besides having these authorities' permission to move forward with the improvement, it would also be beneficial to explore the potential pairing between this proposed improvement with other (government) projects. Hence, the improvement could be more beneficial for all parties. 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 closer to the caldera edge (where higher wind speeds are expected) during the feasibility stage. This can be done by a geotechnical soil investigation (determining soil characteristics such as shear strength, density, permeability, etc.), and subsequently, a soil stability analysis.

- **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:** Lake Toba and the surrounding land is an important tourist destination and could be affected by the wind turbines nearby with a tip height of more than 200 m. 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:** It is expected that near threatened, vulnerable, endangered, and critically endangered flora and fauna species are present in the envisioned wind farm area. Hence, 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 92 MW of wind energy (with variable output), and that the substation in Sidakalang 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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