REPORT

Wind Energy Development Prospectus:
192 MW Project in Kediri, East Java

2024

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

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1 Introduction of the Wind Farm Prospectus

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

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

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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

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

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

2 Analysis of Kediri Wind Farm, East Java – 192 MW

2.1 Introduction of the wind farm location

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

2.1.1 Geographic location

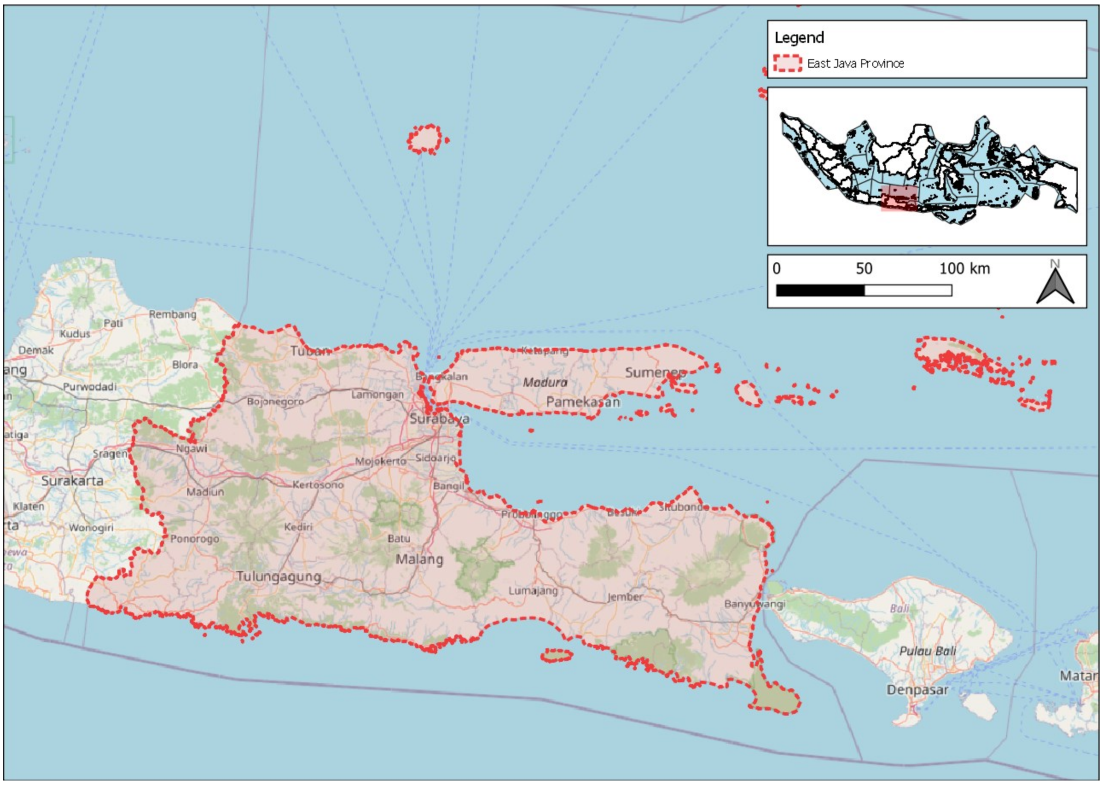

Figure 1. A map of East Java province in which the envisioned Kediri wind farm area is located.

Figure 1 shows the East Java, a province situated in the eastern end of Java Island and in the west of Bali Island. On the island, the province is bordering with Central Java province. The eastern tip of East Java is where the Bali Strait is located. East Java has an area of 48,037 km^2. In 2022, the population in this province amounts to roughly 41.1 million[1], making it the third most populous province in the country[2]. In terms of GDP per capita, the province is ranked 11th (IDR 66.36 million)[3]. Moreover, the economic growth in 2023 (c-to-c) is 4.95%[4]. To provide context, Indonesia's economic growth in that year is 5.05% (c-to-c)[5].

[1] https://jatim.bps.go.id/indicator/12/375/1/jumlah-penduduk-provinsi-jawa-timur.html
[2] https://sulut.bps.go.id/indicator/12/958/1/jumlah-penduduk-menurut-provinsi-di-indonesia.html
[3] https://www.statista.com/statistics/1423411/indonesia-per-capita-gdp-at-current-prices-of-provinces/
[4] https://jatim.bps.go.id/id/pressrelease/2024/02/05/1456/ekonomi-jawa-timur-tahun-2023-tumbuh-4-95-persen--ekonomi-jawa-timur-triwulan-iv-2023-tumbuh-4-69-persen--y-on-y---ekonomi-jawa-timur-triwulan-iv-2023-tumbuh--0-89-persen--q-to-q-.html
[5] 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

East Java is one of the biggest economic hubs in central and eastern part of Indonesia. The province contributes to 14% of the national economic growth[6]. There are multiple industrial processing regions in the province, including Surabaya, Sidoarjo, Gresik, Mojokerto, and Pasuruan. New processing facilities are further developed in Nganjuk, Madiun, and Ngawi[6]. Examples of prominent industrial goods produced in East Java are cigarettes, cement, military vehicles, paper, and trainsets. Furthermore, East Java also hosts Indonesia's largest producing oilfield in Cepu block[7], as well as the recently inaugurated Jambaran Tiung Biru gas processing facility.

In East Java, there are 9 Industrial Estates. The top five largest estates by area are the following[8]:

1. Maspion Industrial Estate (1,143 ha)
2. Ngoro Industrial Park (600 ha)
3. Pasuruan Industrial Estate Rembang (558.49 ha)
4. Safe N Lock Eco Industrial Park (372.2 ha)
5. Surabaya Industrial Estate Rungkut (332.35 ha)

It is noteworthy that some of these estates may already have their own, dedicated power plant(s) to fulfill their respective demand for electricity. Meanwhile, there are two Special Economic Zones (SEZ) in East Java, namely, Gresik SEZ and Singhasari SEZ. The former SEZ was inaugurated in 2022 and was planned to host a glass factory, a smelter, and a CPO processing facility. This SEZ is also complemented with 800-ha residential area and 400-ha port area as the area is near the Madura Strait[9]. On the other hand, the latter SEZ began its operation in 2022, and is focused on the development of tourism, digital technology, education, and creative industry[10].

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

1. Singhasari SEZ (10 MW)
2. Bangkalan Industrial Estate
3. Maspion Industrial Estate (200 MVA in 2021-2030)
4. Tuban Industrial Estate (80 MVA in 2025)
5. Bromo-Tengger-Semeru Priority Tourism Destination (2 MVA)
6. CV Sumber Mas Smelter (9.8 MW in 2021)
7. PT Freeport Indonesia Smelter (150 MW in 2023)

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

[6] https://www.kompas.id/baca/nusantara/2023/11/19/menakar-resiliensi-ekonomi-jatim-ditengah-resesi-global-dan-tahun-politik
[7] https://www.esdm.go.id/en/media-center/news-archives/terbesar-di-indonesia-produksi-minyak-lapangan-banyu-urip-capai-30-produksi-nasional
[8] https://regionalinvestment.bkpm.go.id/pir/kawasan-industri-kek/
[9] https://www.jiipe.com/en/home/kawasanDetail/id/1
[10] https://singhasari.co.id/aktivitas/

It is noteworthy that there is a strip of mountains across the mid-southern part of East Java. Among others, the mountains include Mount Liman, Mount Kawi, Mount Arjuna, Mount Bromo, Mount Semeru, and Mount Argopuro. The presence of these mountains can result in interesting wind characteristics in the surrounding regions. As part of this study, the wind characteristics in four regencies (Kediri, Ponorogo, and Probolinggo – Lumajang) are analyzed. In this prospectus, the considered wind farm location is located in Kediri Regency.

2.1.2 Status in RUPTL PLN 2021-2030

Figure 2 portrays the electricity system of East Java. The system is supported by 500 kV, 150 kV, and 70 kV transmission lines. Furthermore, the system is connected to Madura Island, which is located in the northeast of the province. It is envisioned that in 2025 there will be a 500 kV transmission line connecting Java Island and Bali Island through East Java[11], as shown in the right part of the figure. According to RUPTL PLN 2021-2030, the peak load of this province in 2020 is 5,935 MW. Meanwhile, the level of energy production and peak load is projected to increase steadily in 2021-2030, as shown in Figure 3. This projection is based on the assumption that the average demand growth rate will be 3.7% per year.

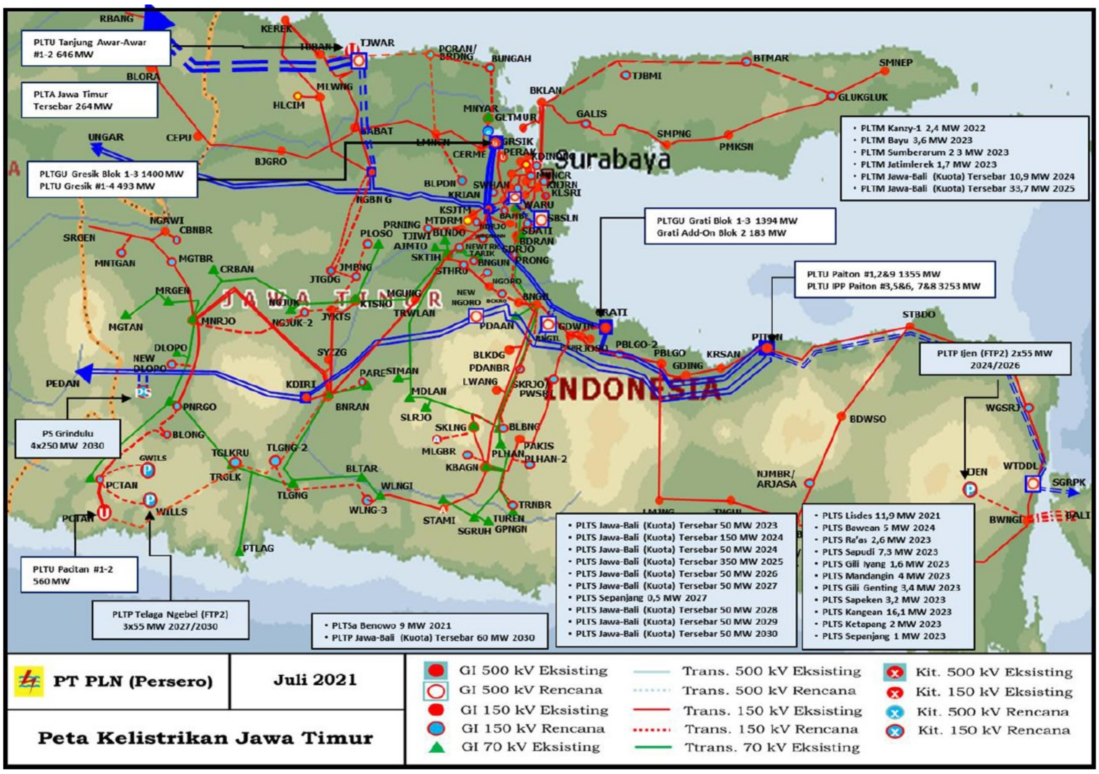

Figure 2. A map of East Java electricity system in RUPTL (Source: RUPTL PLN 2021-2030).

[11] https://web.pln.co.id/media/siaran-pers/2022/12/pln-siapkan-pembangunan-transmisi-listrik-jawa-bali-target-proyek-rampung-2025

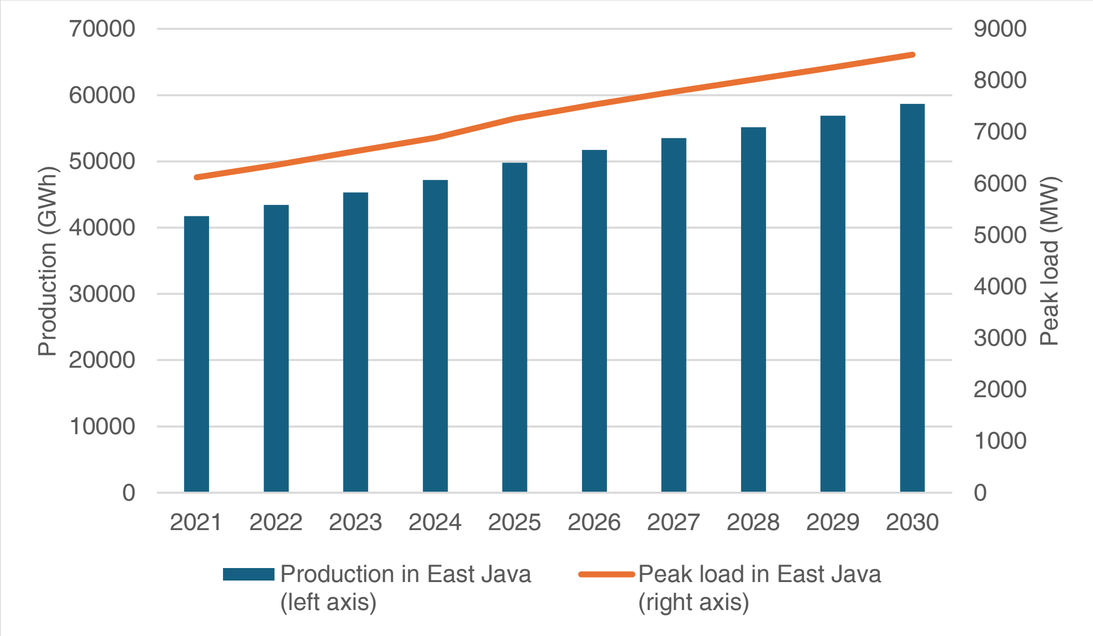

Figure 3. Projected electricity production and peak load in East Java (Source: RUPTL PLN 2021-2030).

A summary of the power generation development planning can be seen in Figure 4. This figure includes both conventional and renewable energy power plants. Additional power generation is categorized into two sources, namely, PLN and Independent Power Producer (IPP). There is no allocation for wind energy in 2021-2030. However, the RUPTL identifies the following wind power potential in East Java:

- Banyuwangi (75 MW)
- Probolinggo (50 MW)
- Tuban (66 MW)
- Tuban (140 MW for solar and wind farm)

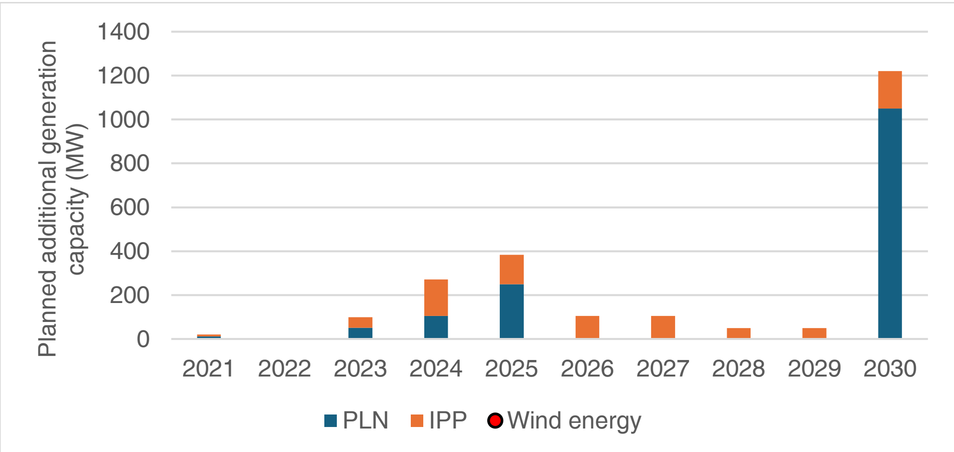

Figure 4. Additional generation capacity being planned for East Java (IPP: Independent Power Producer; Source: RUPTL PLN 2021-2030).

2.1.3 Status of development

There are some ongoing development activities for wind energy in East Java. At the end of 2023, one developer is known to have initiated their development and in the process of obtaining permit in Blitar Regency[12], which is near the southern coast of East Java. In early 2023, a private investor is said to be studying the feasibility of building a wind farm in the coastal area of Munjungan in Trenggalek Regency[13]. Finally, in 2020, PLN were planning to build a 50 MW wind farm in Banyuwangi Regency after having completed their feasibility study[14]. The construction was planned to start in 2021[15], however, there is no further updates on its continuation up to the time of writing.

2.2 Wind resource availability and land use

2.2.1 Approach

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

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

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

The next step was to consider the “go/no-go zones.” As the name suggests, these zonal categories indicate whether a particular area either can accommodate wind farm developments without significant restrictions/conditions to be fulfilled (go zone), can accommodate wind farm developments with significant restrictions/conditions to be fulfilled (go zone with restrictions), or cannot accommodate wind farm developments (no-go zone).

[12] https://surabaya.kompas.com/read/2023/12/22/153732378/pemkab-sebut-investor-china-akan-bangun-pltb-rp-125-triliun-di-blitar
[13] https://jatim.antaranews.com/berita/673947/investor-jajaki-potensi-pengembangan-pltb-trenggalek
[14] https://news.detik.com/berita-jawa-timur/d-4912684/pln-akan-bangun-pltb-di-banyuwangi-diklaim-terbesar-di-pulau-jawa
[15] https://www.antaranews.com/berita/1946676/pemkab-banyuwangi-indonesia-power-kembangkan-listrik-tenaga-bayu

These zones were determined considering the land use, i.e. presence of nature reserves, protected areas, and airports, as well as water ways and water bodies, based on OpenStreetMap (OSM). Furthermore, existing policies (e.g. spatial plans) and regulations (e.g. on permitting) specific to the area are also considered.

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

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

2.2.2 Wind resource and characteristics

Figure 5 shows the initial search area (bounded by the purple-dash box) in the Kediri Regency. Within the figure, areas with average wind speeds of more than 6 m/s are indicated by the "pixels" with distinct color as described by the color bar. It can be concluded that promising wind resources are located in a particular area in the regency. Moreover, higher wind speeds are present near Mount Liman.

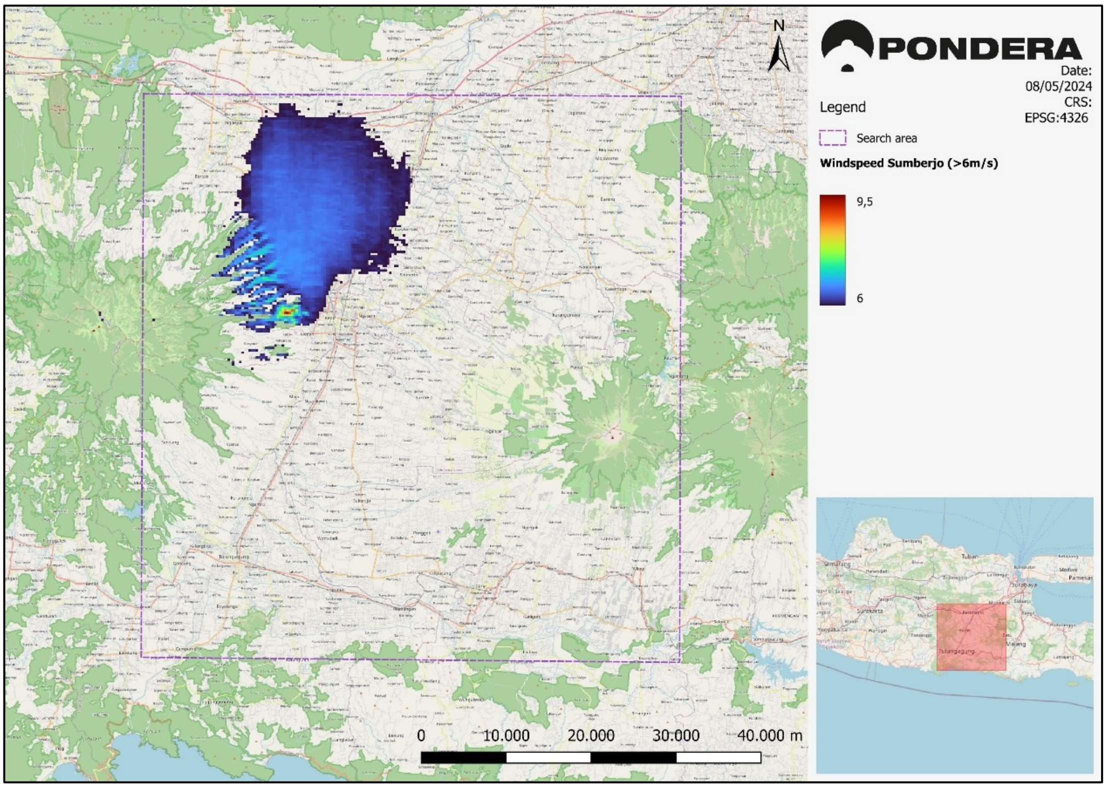

Figure 5. Kediri search area with wind speed distribution. The purple-dash bounding box shows the full search area. The color bar indicates average wind speeds which are above 6 m/s at 100 m height according to the Global Wind Atlas (GWA) climatology.

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.

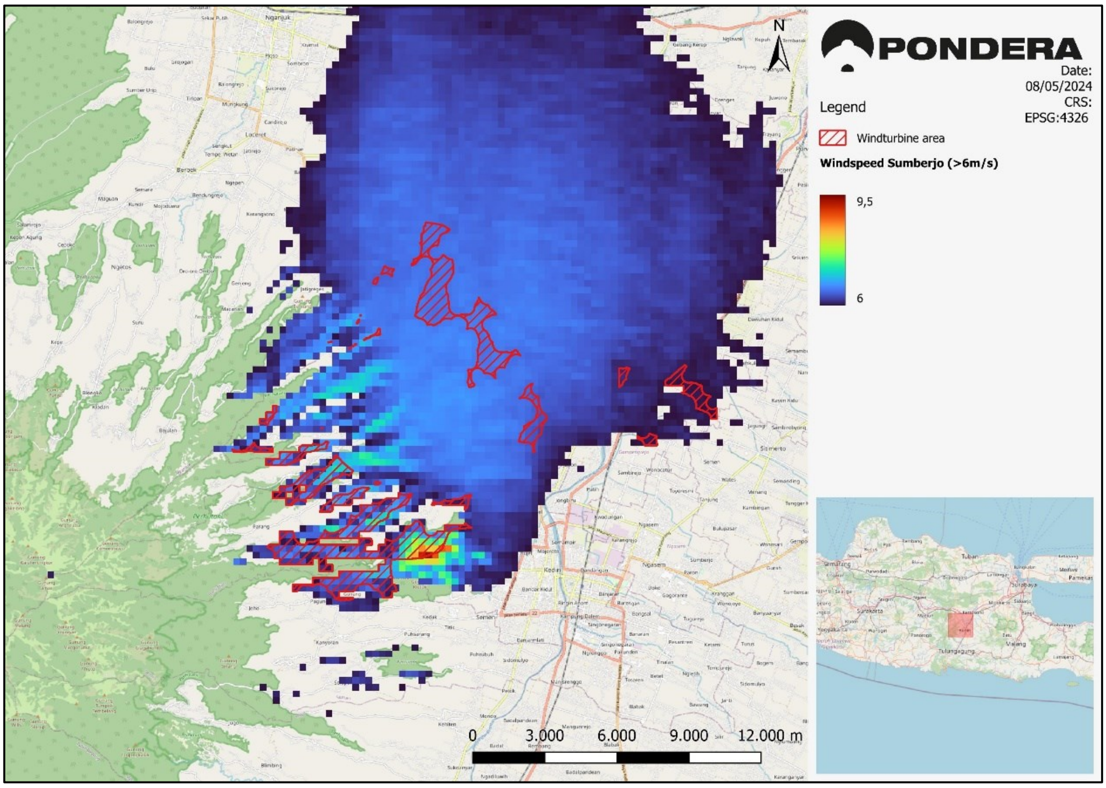

Figure 6. A zoomed-in look at the Kediri search area along with the wind speed distribution. The red, dashed polygons represent the final WTG-area which meets all the criteria. Average wind speeds above the threshold of 6 m/s at 100 m height according to GWA are shown.

Additionally, Figure 7 visualizes the long-term average wind direction distribution for the Kediri area. As can be interpreted from this figure, the wind climate in the area primarily consists of wind from the south 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 June 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 south wind directions. Approximately from November until May (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.

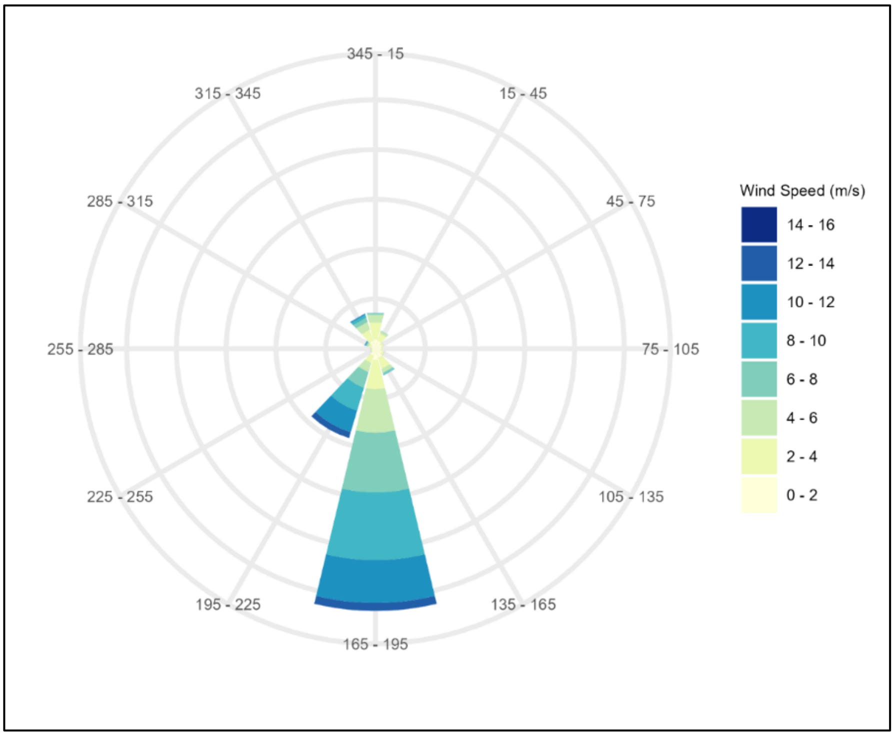

Figure 7. Wind rose diagram with wind directions and wind speed categories based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

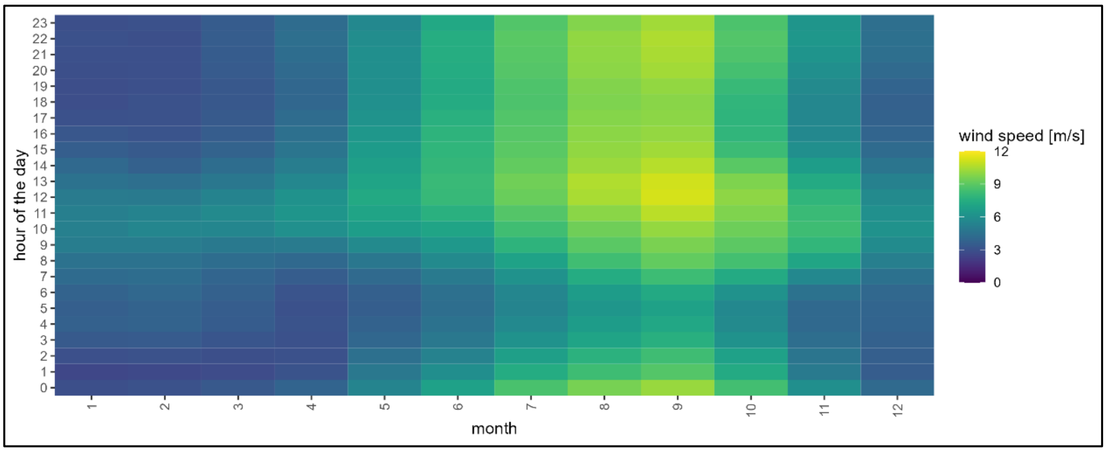

Figure 8. The wind speed distribution throughout the day, visualized per month of the year. Based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

2.2.3 Topography

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

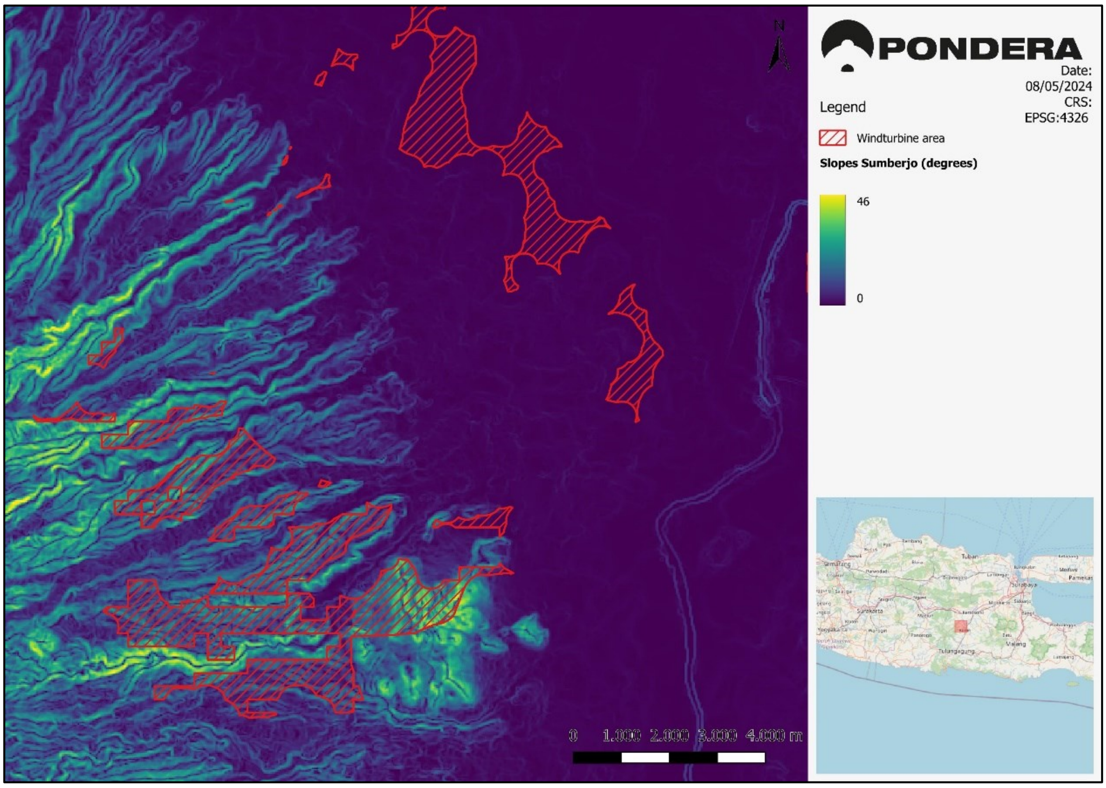

Figure 9. Topography of the Kediri WTG-area, showing the slope (in degrees; according to calculated based on FABDEM data) at the region.

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 area. 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.

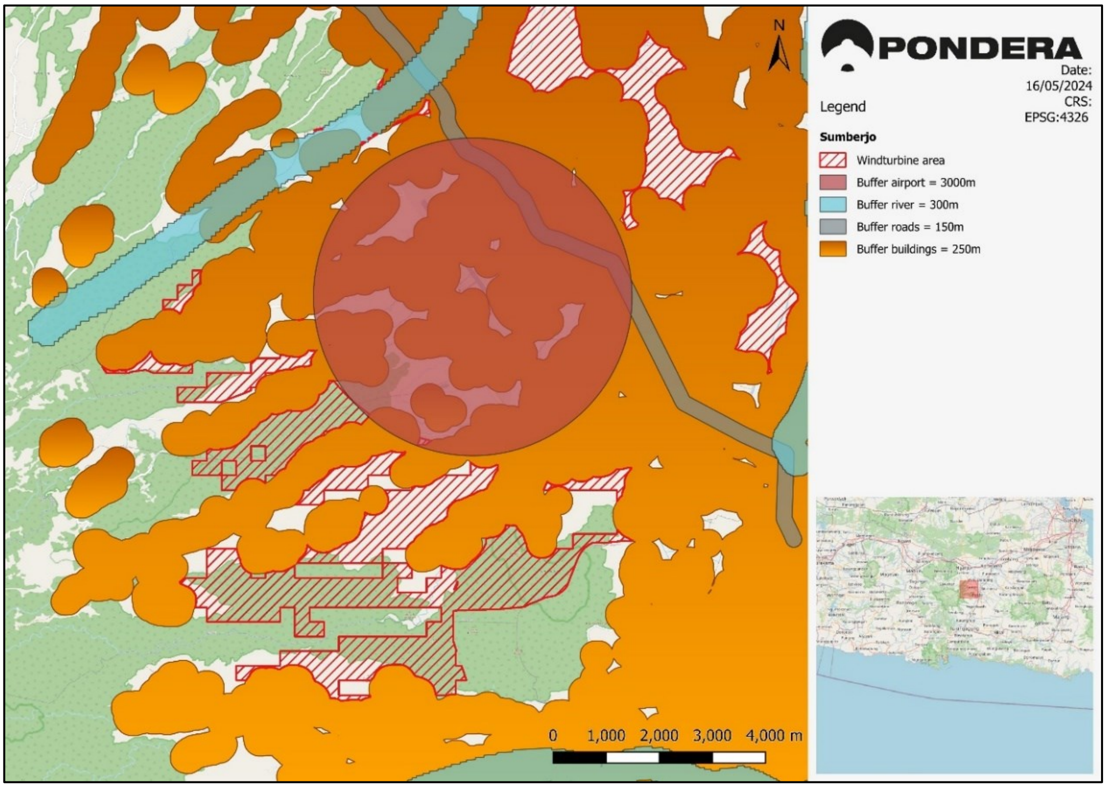

Figure 10. Exclusion zones at the Kediri area based on land use and residential areas. Source: ESRI and OSM.

2.2.5 Specific permitting requirements

The analysis in this subsection was done by referring to the Kediri Regency Spatial Plan (*Rencana Tata Ruang Wilayah* or RTRW) 2011-2031. As shown in Figure 11, the continuous area with promising wind speed is located in the following land use types:

1. Plantation Area (*Kawasan Perkebunan*)
2. Dryland Agriculture/Farming Area (*Kawasan Pertanian Lahan Kering*)
3. Wetland Agriculture/Farming Area (*Kawasan Pertanian Lahan Basah*)
4. Urban Settlement Area (*Kawasan Permukiman Perkotaan*)
5. Rural Settlement Area (*Kawasan Permukiman Pedesaan*)

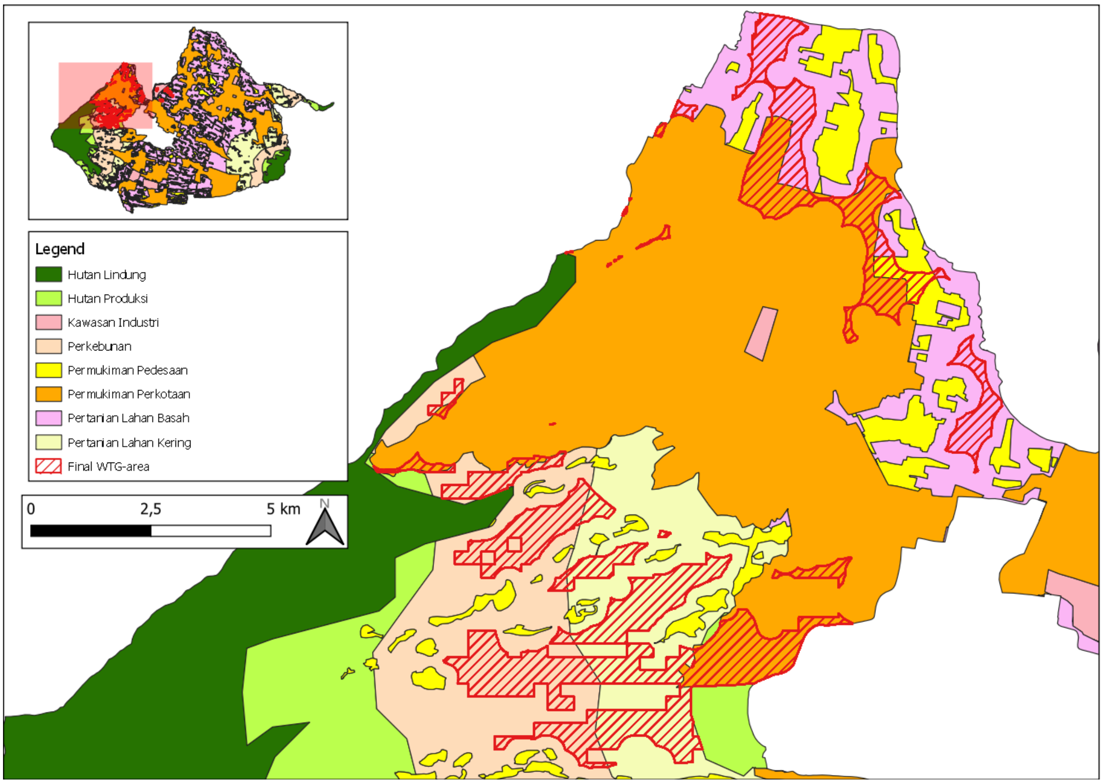

Figure 11. The map of spatial planning of Kediri Regency (RTRW 2011-2031) is overlaid with the final WTG-area.

Parts of the final WTG-area which are located in the Plantation Area are usually owned by either a (private or state-owned) company or the local community. The former case is typified by the cultivation of a single type of plant. Conversely, in the latter case, the area is usually cultivated with several types of plants. If the area is not part of the Sustainable Food Agriculture Area (*Kawasan Pertanian Pangan Berkelanjutan*/KPPB), then the Plantation Area can be used for wind farm development (and other types of power generation and transmission activities for public interest) once a purchase or lease agreement is obtained with the landowner[16].

Some parts of the final WTG-area overlap with Dryland Farming/Agricultural Area and Wetland Farming/Agricultural Area. Ownership of this piece of land is also not yet known for this study. Therefore, it is reasonable to assume that the land is either owned by the community, private companies, or state-owned companies. Wind farm development in this area is possible if the area is not part of the Sustainable Food Agriculture Area, and after purchase or lease agreement is reached with the landowner[16].

Parts of the WTG-area that are in both Urban and Rural Settlement Areas are assumed to belong to the community. Construction of wind power plants at these locations is possible as long as a purchase or lease agreement is achieved with the landowner.

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

As will be shown later in Section 2.3, locations of the envisioned wind turbines within the final WTG-area are mostly located in Plantation Area, Dryland Farming/Agricultural Area, and Urban Settlement Area. Consequently, the cost associated with using these three types of land use will be considered in the business case calculation (see Section 2.9).

At the time of writing, Dhoho Airport in Kediri Regency has just recently been inaugurated (April 2024). Although a 3,000 m buffer around airports was added to the exclusion (no-go) zones, it is important to check in a subsequent study whether the envisioned wind farm overlaps with the Aviation Operations Safety Area (KKOP) of this airport.

It is worth noting that the RTRW of Kediri Regency obtained is for the year 2011-2031. Based on the information obtained, the Kediri Regency Government revised the RTRW in 2020, and it is possible that a Regional Regulation regarding the RTRW has been issued. If the new Regional Regulation on RTRW has been issued, the analyzed RTRW above is no longer valid. It is therefore necessary to seek confirmation from the authorized agencies of Kediri Regency.

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.

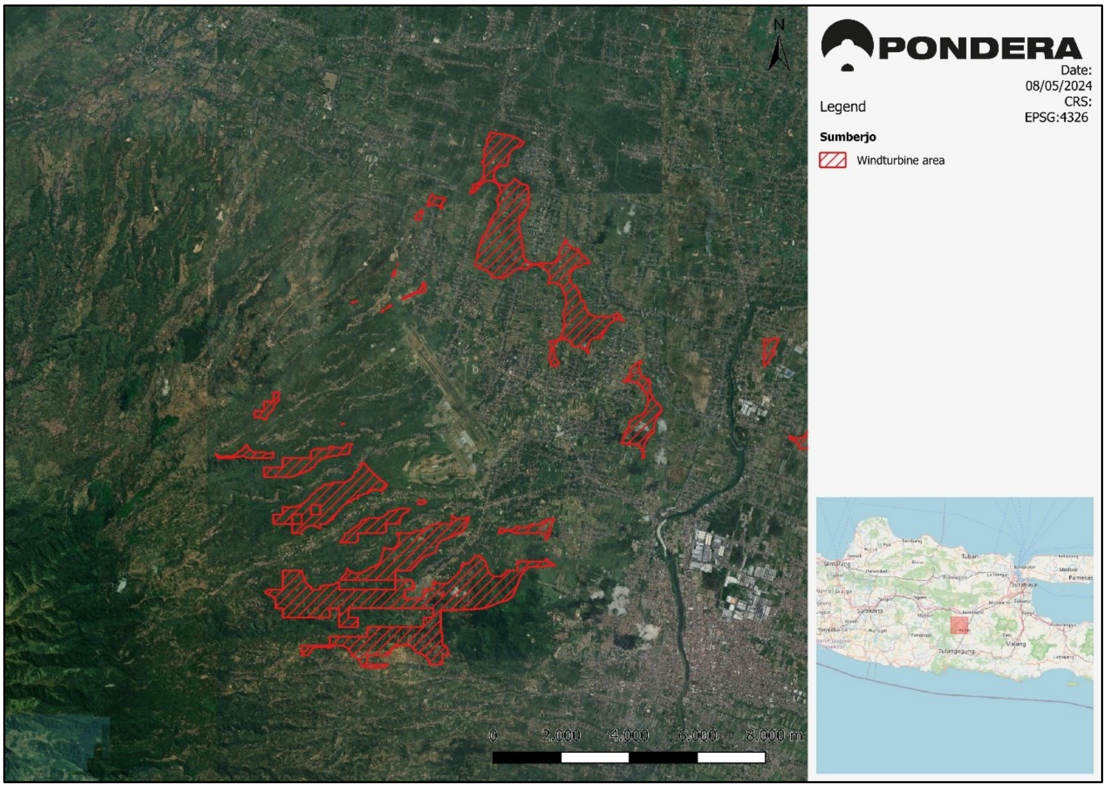

Figure 12. Final WTG-area based on the restriction criteria. Source: Google Satellite Images.

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.

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.

The WTG-area is divided into two parts: the southwestern area on the slope, and the northeastern area which is located in a more urban area. In the southwestern part, we expect less conflicts with building infrastructure. Therefore, we have selected this southwestern part of the WTG-area for further analysis, also due to the more promising wind climate.

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.

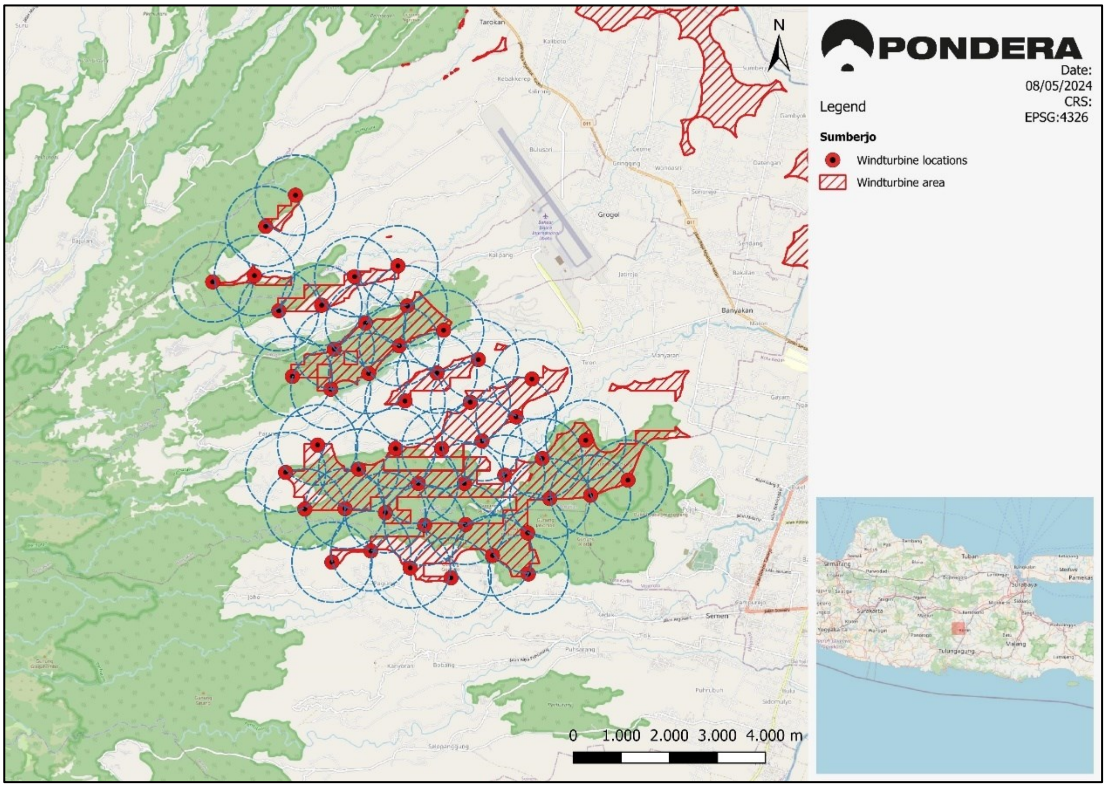

Figure 13. Preliminary wind farm layout at the final WTG-area.

Figure 13 displays an overview of the wind turbine locations in the final WTG-area. A total of 48 wind turbines were positioned into the area, amounting to an envisioned total installed capacity of 192 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 and the few available highways, 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. However, for this particular site, transport might be less of an issue as a highway exit is planned right at the base of the envisioned wind farm. The transport might be considerably easier at this site compared to other sites on Java and Sumatra.

2.4.2 Port-to-site transportation

All major ports of Java are located on the north coast, bordering the calmer Java Sea compared to the Indian Ocean on the south coast. Most of the long-distance transport of goods is done via the northern part of the island. Port of Surabaya (i.e. Port of Tanjung Perak) is the nearest major port, at a distance of about 100 km from the site (see Figure 15). From Port of Surabaya, an access point of the highway is located right at the entrance/exit of the port.

Figure 15. A satellite image of the Port of Surabaya. Entry/exit road at the western part of the port and entry of the highway are in line, which makes this port suitable for transportation of long wind turbine components.

When one or more of the envisioned wind farms in East Java are constructed, transport for all sites via one access point (Surabaya) may have advantages (i.e. contacts with port and authorities, contracts, port investigation, temporary storage which can be reused, etc.).

From Surabaya, a toll road system is finished until ~25 km north of the site (see Figure 16). From there, a planned toll road Kediri - Kertosono is in preparatory phase. According to news articles, in the beginning of 2024, the project was in the phase of land acquisition. This new toll road from Kertosono to Kediri will have a connection to the new Dhoho airport of Kediri. A short section of this connection on the airport side has already been finished. This access road from the airport to the highway will have several entrances along the way. One of these proposed entrances will connect to Jl. Panglima Besar Sudirman, which is the nearest larger road at the foot of the hills where the wind farm is envisioned.

From the port to this entry point, no road upgrades are expected as the toll roads and access roads are wide in all sections. However, a limiting factor may be the height of the numerous bridges over the toll roads. The available signs are unclear about the clearance as both signs of 4.2 m (on the bridge) and 5.1 m (side of the road) are being shown. This height is particularly important for the diameter of the base of the turbine tower, as this height can limit the diameter of the base that can be used. The base is normally transported horizontally, and manufactured as one piece.

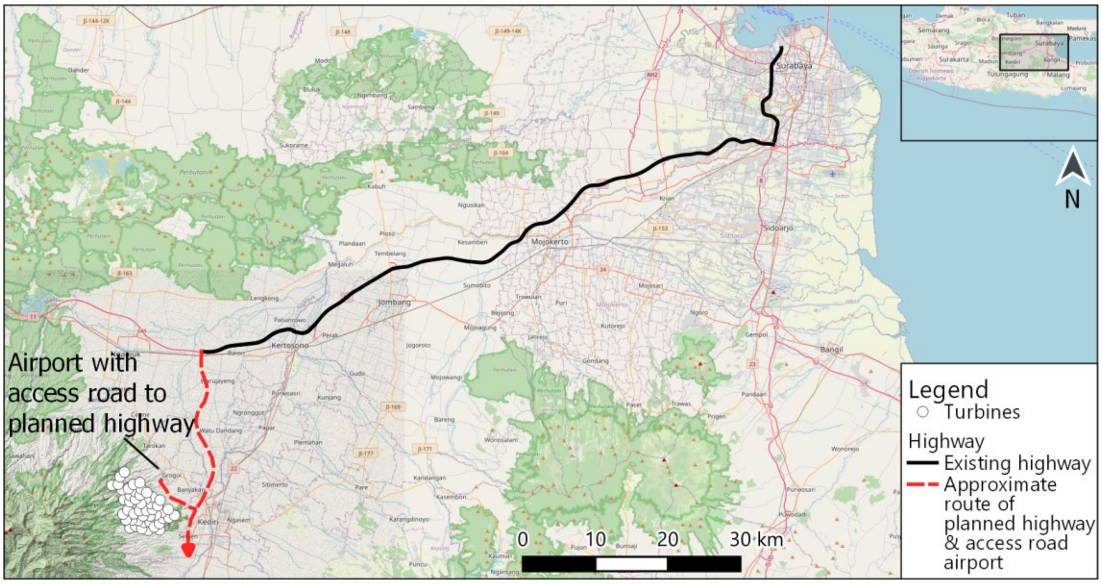

Figure 16. Route from toll road to site. The planned highway is in the land acquisition phase. The route of the planned highway is not exact, as detailed maps were not found.

Based on a rather rudimentary method (see Figure 17), a height of ~6 m between road surface and bridge was derived (3.5x Toyota Innova Reborn of 1.795 m height according to its specifications, which equals to 6.3 m). While this method is not completely reliable, the height seems to be much more than the shown maximum height of 4.2 m.

Figure 17. The height of bridges above road surface seems to be more than 4.2 m. As a comparison, this Toyota Innova Reborn's height is 1.795 m according to specifications.

As the exit of the highway is situated at the beginning of the access road, it is expected that no bridges have to be strengthened. It is assumed that the bridges on the highway from Surabaya, and on the entry points to the highway are strong enough.

2.4.3 Transport within the site

Within the site, the roads down in the valleys connect the different villages. As the wind turbines are envisioned on top of the ridges, using these roads is not cost effective. For the most parts, new roads will have to be constructed. At the foot of the ridges, some parts of the existing roads can be used. Most of the existing roads are connected to the new road surrounding the airport, which will be connected to the highway access road.

As shown in Figure 18, a total of 58.7 km of new roads will have to be constructed, and 11 km of existing road has to be upgraded (shown as blue lines; also see Figure 19). Of the new road, a 16.3 km section leads through steep terrain (shown as red lines). In this terrain, the road will have to be cut into the side of the hills, which results in higher amounts of cut & fill. The other part (42.4 km; shown as orange lines) can be constructed on top of the hills or in the valleys.

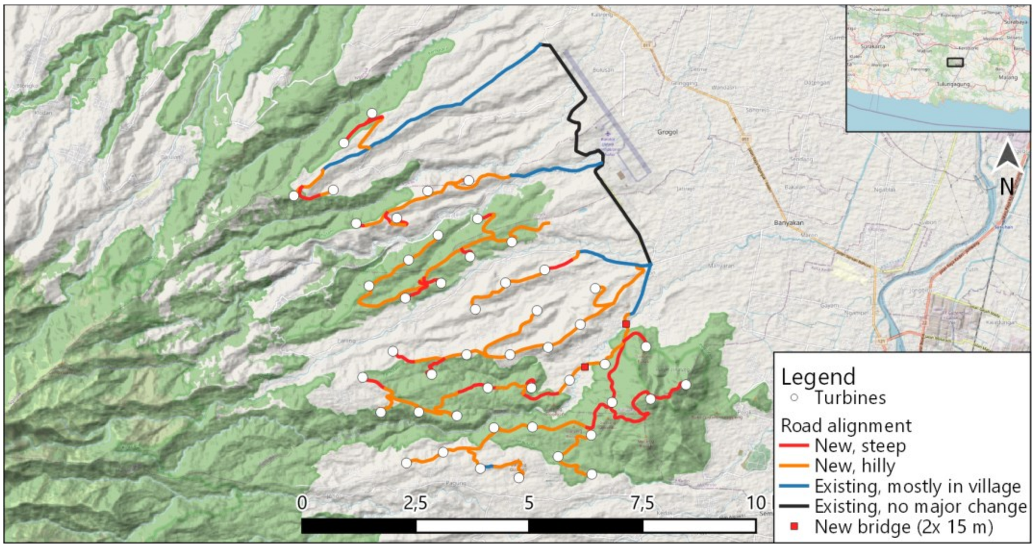

Figure 18. Road layout within site. Part of the black existing road on the airport terrain might be in private hands. Black road is part of the connection of airport to the planned highway, and will be connected in later stages.

Near the airport, several large roads are located between the wind farm access roads and the yet-to-be-built entry road to the highway (shown as black lines; also see Figure 19). The airport has a private owner (Gudang Garam), and is operated by PT Angkasa Pura II (state-owned company managing airports in Indonesia). It might be that the road leading to, and surrounding the airport is in private ownership as well.

Figure 19. (Left) Roads within the village as shown by the blue lines in the previous figure, and (right) roads surrounding the airport as shown by the black lines in the previous figure.

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

- Inquire or measure accurate heights between road surface and bridges on toll roads. The height of the lowest bridge may be a limiting factor of the diameter used for the base of the turbine tower;
- Inquire about planning of toll road construction from the existing toll road (Surabaya-Solo) to Kediri; and
- Inquire about possible usage of the road surrounding the airport, as this might be in private hands.

2.5 Geology and seismicity conditions

The envisioned wind farm is located on the eastern slopes of Mount Wilis. This is a sleeping volcanic complex, without known recent eruptions (major eruptions are generally known since ~1700s). Several other individual peaks (such as Mount Liman) are located within the complex.

2.5.1 Geology

The envisioned wind farm is located on the lower end of the slopes of the Wilis volcano. The geology consists of volcanic breccia with pyroxene andesite fragments, tuff, agglomerate, and pyroxene andesite lava (see Figure 20). At this distance from the main craters of Mount Willis, no major deposits of igneous rock/lava flows (harder material) are expected, but only breccia that can be dug by an excavator.

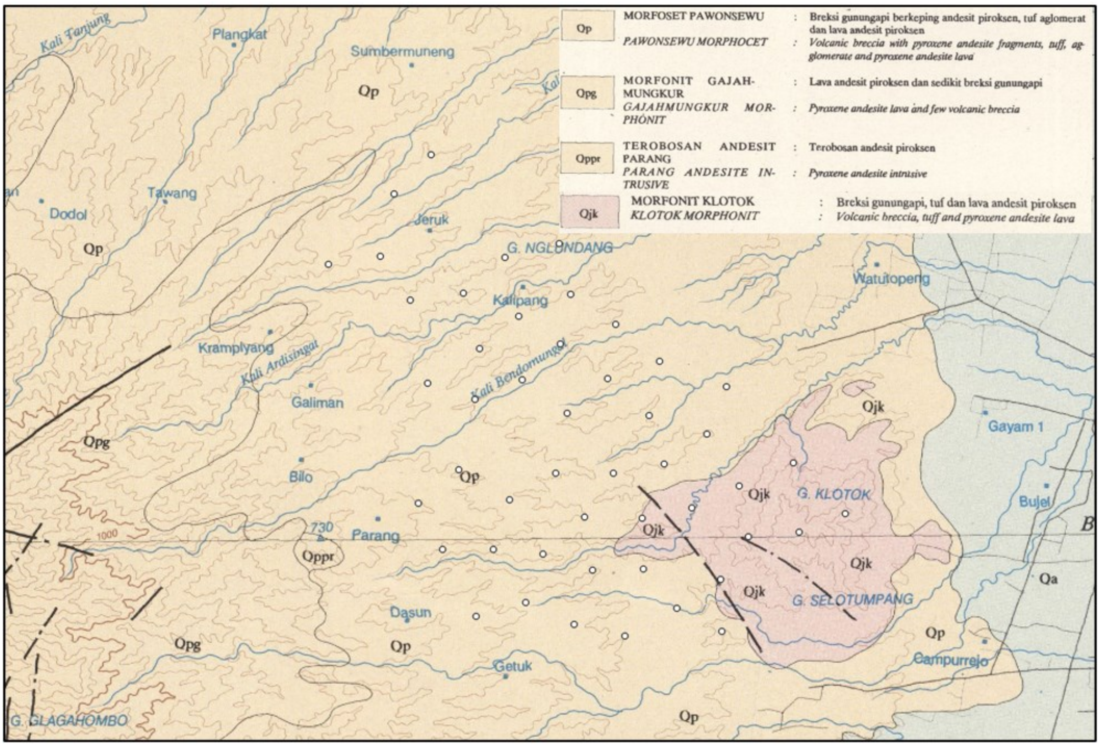

Figure 20. Geological map of the site. Turbines are represented by white dots with black outlines. The colors indicate the geological formations at the surface. All wind turbines are located in Qp or Qjk formations (mainly volcanic breccia).

The southeastern wind turbines are envisioned on or close to Mount Klotok. This is a smaller separate sleeping volcano, consisting of volcanic breccia, tuff, and pyroxene andesite lava. However, as a few turbines are placed close to the center of this volcano, higher volumes of igneous rocks may be present within the layers of breccia compared to the other turbine locations.

This geology combined with the topography makes the wind farm area 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 21 visualizes land movement vulnerability index of the soil in and around the WTG-areas. It can be seen that a combination of vulnerability levels applies to the considered wind farm location. Major parts of the wind farm are in areas with low to medium level of land movement vulnerability.

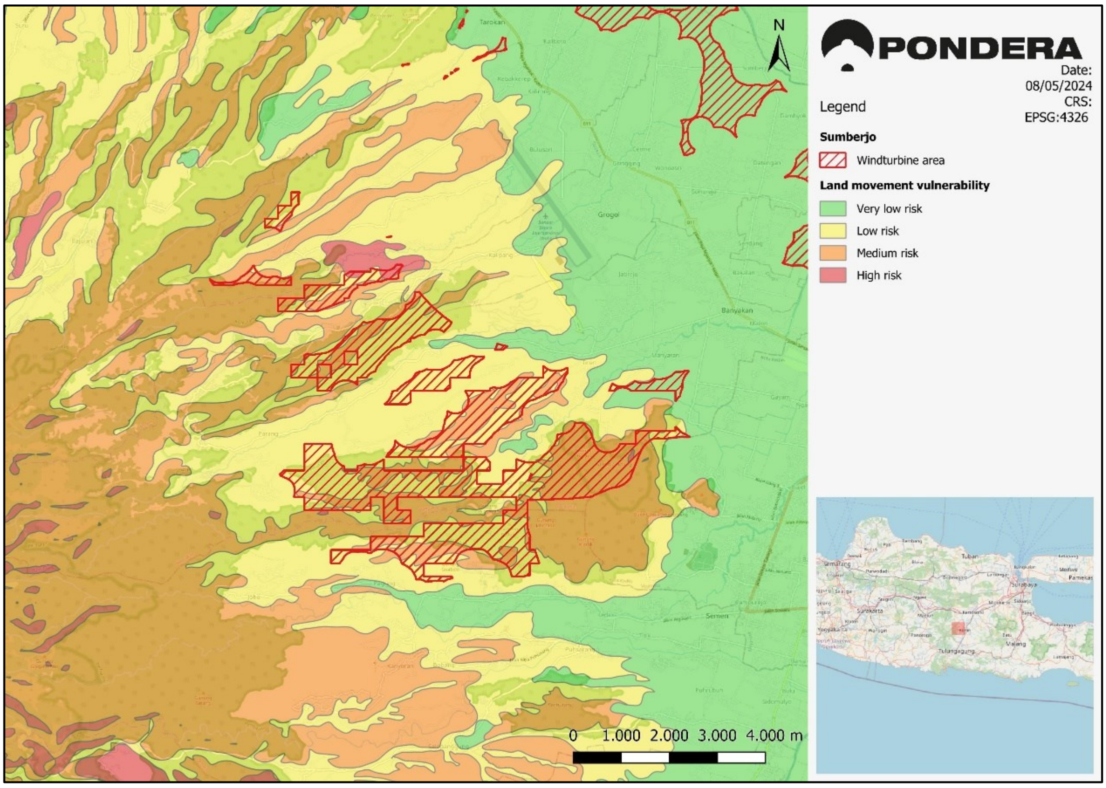

Figure 21. Land movement vulnerability index for Kediri.

The stability and capability of the soil to carry wind turbines 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

According to the geological map (see Figure 20), some faults are observed in the nearby area. These are likely to be related to the past volcanic activity. As the volcanoes are now dormant, no major activity is expected from these faults in this stage of volcanic inactivity. However, geologically speaking, these volcanoes are still young and may become active again.

Apart from these faults, a large subduction zone is situated in the south of Java. The movement in this subduction zone is 7 cm/year, which results in regular earthquakes. Most of these are magnitude 4 to 5, and occasionally higher. According to the USGS, since 1990, three large (>M 7.0) earthquakes occurred south of Java (M 7.0, 7.7, and 7.8).

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 earthquakes with an intensity of VII to VIII on the Modified Mercalli Intensity (MMI) scale. Figure 22 provides a visual representation of the earthquake risk level in and around the WTG-area.

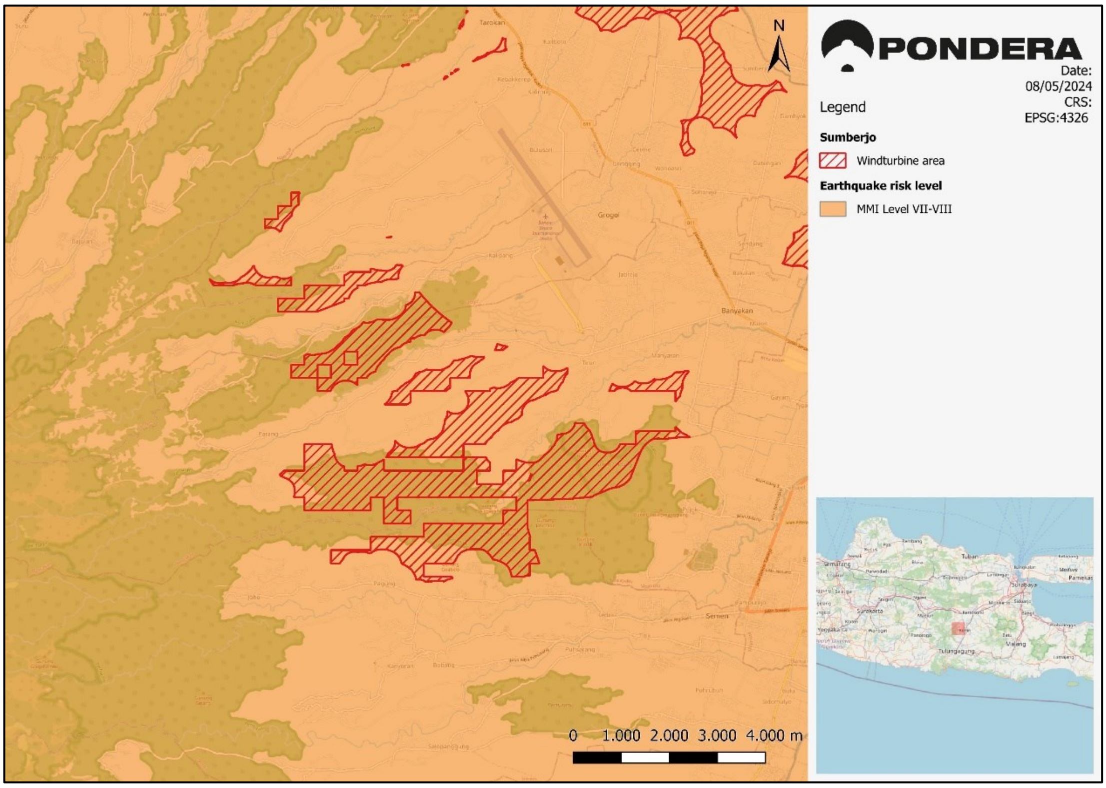

Figure 22. Earthquake hazard and risk level at Kediri.

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

> VII: *"Damage is negligible in buildings of good design and construction; but slight to moderate in well-built ordinary structures; damage is considerable in poorly built or badly designed structures; some chimneys are broken. Noticed by motorists."*
>
> VIII: *"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

Topography and land use are relatively uniform throughout the site. The villages are mostly located in the valleys, surrounded by mainly rice paddies. East-west oriented ridges separate the different valleys and are mostly covered by forest and shrubs, small scale farming, and agroforestry. Some parts of the ridges are managed by Perhutani (State Forestry Public Company). On Mount Klotok, a small section of this forest is a protected forest (*Hutan Lindung*). The general impression of the site is described in the following figures.

Figure 23. This view is from the top of the most southern ridge, with Mount Klotok in the background where some turbines are envisioned. On the left, there is a steep valley separating the ridges.

Figure 24. This view is looking at Mount Wilis. Valleys in between the ridges can be deep and steep. Road construction from one ridge to the other (north to south) has to be avoided.

Figure 25. Villages in wider valleys are surrounded by mainly rice paddies. Ridges on left and right are covered by forest/agroforest and/or small fields.

Figure 26. This view is looking down at the two ridges, with the airport in background. Hills are covered in small fields, forest, and shrubs.

Figure 27. These are the slopes leading to the summit of Mount Klotok. Slopes on the north, west, and south side of the mountain are irregular and difficult to build access roads on.

2.6.2 Biodiversity and environmental impact

In the valleys, almost all areas are used for agricultural activities. The slope and top of the hills are covered by forests (non-protected, but managed by Perhutani). Throughout the area, small scale farming and/or agroforestry takes place on the ridges. Part of Mount Klotok is a protected area (*Hutan Lindung*). During the site visit, no primary forest has been observed, but some small patches may still be present.

In the Spatial Plan of Kediri City (*Peraturan Daerah* Kota Kediri No. 1/2012: RTRW Kota Kediri 2011-2030), Mount Klotok is named a 'touristic forest', and is also referred to as an area of increased erosion risk and strategic water catchment area. It does not seem to be protected from a biodiversity standpoint.

As humans are active throughout the area, it is expected that these areas are not the highest ranked areas in terms of biodiversity. The forest managed by Perhutani seems to be 'unused' and many farmers' fields are present in these forests. This means that habitats of animals in these forests are already cut up into small sections. The main impacts of wind farm development are:

Biodiversity impact:

- Bird & bat strikes (turbines)
- Further habitat fragmentation (mainly by new roads and transmission lines)

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 large scale human presence and influence in the region, it is expected that extra impact due to wind farm construction is mainly limited to bird & bat strikes and visual impacts.

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 28) 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[17]. 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).

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

Figure 28. The area in which the abovementioned flora and fauna has been observed (covering the envisioned wind farm location). All of these observations are categorized as at least 'least concern'.

The two bird species *Enicurus ruficapillus* (near threatened) and *Geokichla interpres* (endangered) were observed in the 1930s, and based on a preserved specimen. It is unknown whether these species are still present in the area, but they are not in the database as an observed species in more recent times. 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
Alcedo euryzona	Blue-banded Kingfisher	Critically endangered (CR)
Nisaetus bartelsi	Javan Hawk-Eagle	Endangered (EN)
Ptyas korros	Chinese Ratsnake	Near threatened (NT)
Rhacophorus reinwardtii	Reinwardt's Flying Frog	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
Pinus merkusii	-	Vulnerable (VU)

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 or feasible, such as the existing access roads within the area;
- Avoid construction of roads and/or powerlines in such a way that existing forest is cut up into separate sections, and use the same layout for road and the electrical grid between the turbines to avoid habitat fragmentation; 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. During the feasibility stage, the possibility of construction in the protected area in Mount Klotok should be explored further.

2.6.3 Social impact

Several villages are located in the valleys, in between the ridges (see Figure 29). The potential turbines are placed on the slopes or at the top of the ridges, away from these villages at a distance of at least 300 meters.

The villages within the wind farm lie close to Kediri. The most eastern villages can be seen as outskirts of Kediri as they make up one continuous built up area. The villagers consist of small scale farmers and small shop owners. As the city is close by, most workers seem to commute to Kediri.

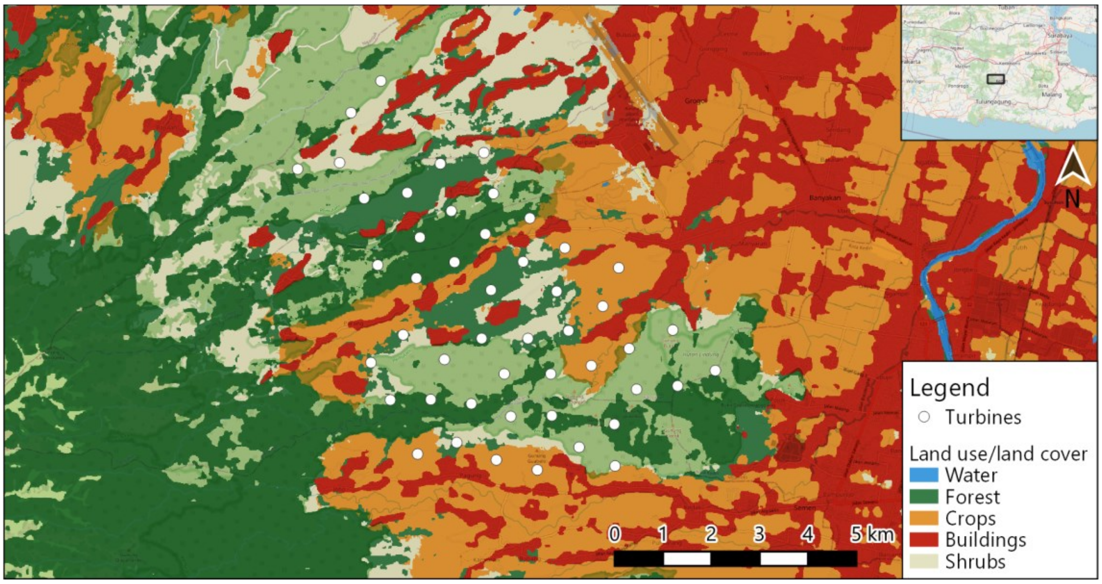

Figure 29. Land use map based on satellite imagery (ESRI/Sentinel 2, 2023). The area directly around the wind turbines is primarily covered by forest and shrubs. Villages and crops are concentrated in the valleys.

The social impact can be divided into several aspects:

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

As the turbines are mostly built on unpopulated ridges/hills away from the villages, the social impact is mainly limited to the loss of agricultural land and visual impact. Most of the access roads to be built are in unpopulated areas (on top of the ridges). This will reduce the amount of construction works (temporary obstruction) on existing roads. However, if the access roads are open to the public, they will also have little impact on the mobility of the population living in the area, as the roads do not lead through the villages.

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

Population

The graph of population and annual population growth rate is shown in Figure 30. The annual population growth rate of the regency increased from 0.74% in 2021 to 0.79% in 2023. The population also increased from 1,644,400 people in 2021 to 1,677,170 people in 2023.

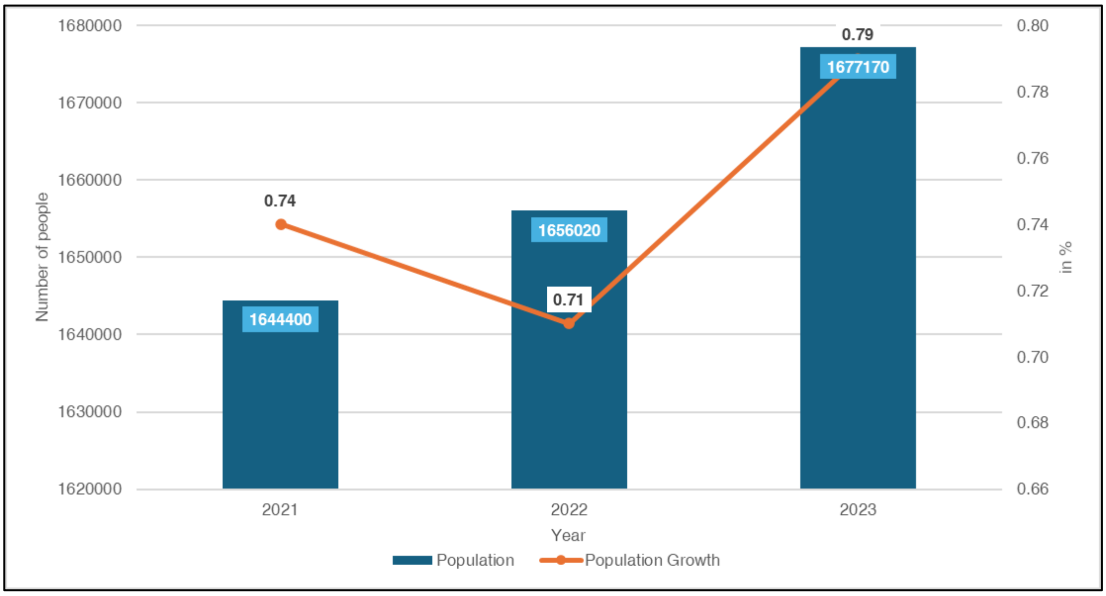

Figure 30. Population and annual population growth rate in Kediri in 2021-2023 (Source : BPS Kabupaten Kediri).

The regency's population pyramid is shown in Figure 31. Moreover, the gender ratio in Kediri is 1.02 in 2023.

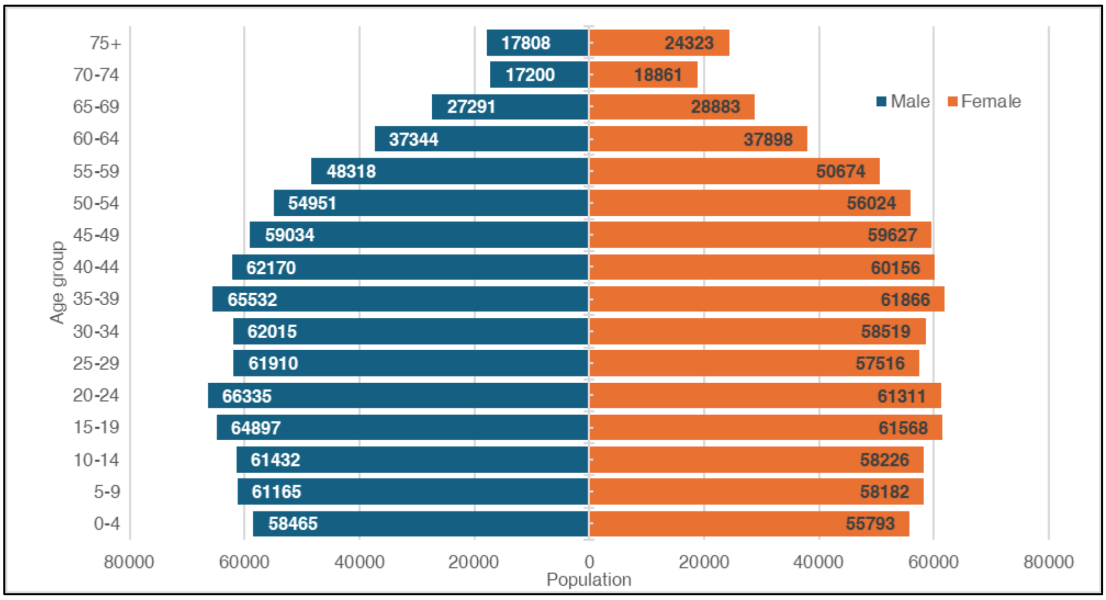

Figure 31. Population pyramid in Kediri Regency in 2020 (Source: BPS Kabupaten Kediri).

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. These rates are displayed in Table 3. During 2021-2023, the regency's labor force participation rate dipped, whereas the unemployment rate slightly increased.

Table 3. Labor force participation rate and unemployment rate in Kediri Regency in 2021-2023 (Source: BPS Jawa Timur).

Metric (in %)	Year		
	2021	2022	2023
Labor force participation rate	69.34	68.73	68.74
Unemployment rate	5.15	6.83	5.79

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

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

Educational attainment	Working	Unemployed	Total of Economically Active	Percentage of Working to Economically Active
Primary school (SD)	335,616	10,376	345,992	97.00
Middle school (SMP)	198,719	12,547	211,266	94.06
High school (SMA)	254,052	24,517	278,569	91.20
University	69,337	5,313	7,465	92.88
Total	**857,724**	**52,753**	**910,477**	**94.21**

The pure participation rate in demographic data represents the ratio of enrollment for the age group corresponding to official school age in primary or secondary levels, to the total population of the same age group in a given year. These rates are shown in Table 5.

Table 5. Pure participation rate in Kediri Regency in 2021-2023 (Source: BPS Kabupaten Kediri).

Pure participation rate	Year		
Educational level	**2021**	**2022**	**2023**
Primary school	98.77	97.26	97.53
Middle school	87.12	86.65	88.53
High school	68.77	69.12	72.75

Table 6 shows the number of educational facilities in Kediri Regency. Among the different education levels. The largest number of educational facilities is that of playground (TK), followed by primary school (SD), middle school (SMP), and senior high school (SMA/SMK). Additionally, the total number of universities is recorded to be eight units.

Table 6. Educational facilities in Kediri Regency in 2021 (Source: BPS Kabupaten Kediri).

Type of school	Number of facilities
Primary school (SD)	342
Middle School (SMP)	143
High School (SMA)	64
Vocational School (SMK)	42
University	8

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

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

Human Development Index in Kediri Regency from 2021 to 2023 has an increasing trend, as shown in Table 7.

Table 7. Human Development Index, Gender Empowerment Index, and Gender Development Index in Kediri Regency in 2021-2023 (Source: BPS Kabupaten Kediri and BPS).

Metric	Year		
	2021	2022	2023
Human Development Index	73.31	74.20	74.68
Gender Empowerment Index	71.64	73.20	73.36
Gender Development Index	92.90	92.85	93.25

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, despite the slight dip in 2022, 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 Surya Zig Zag 150 kV substation is selected for this, located in the north of the village of Kediri. The aerial photo of this substation is included in Figure 32. 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.

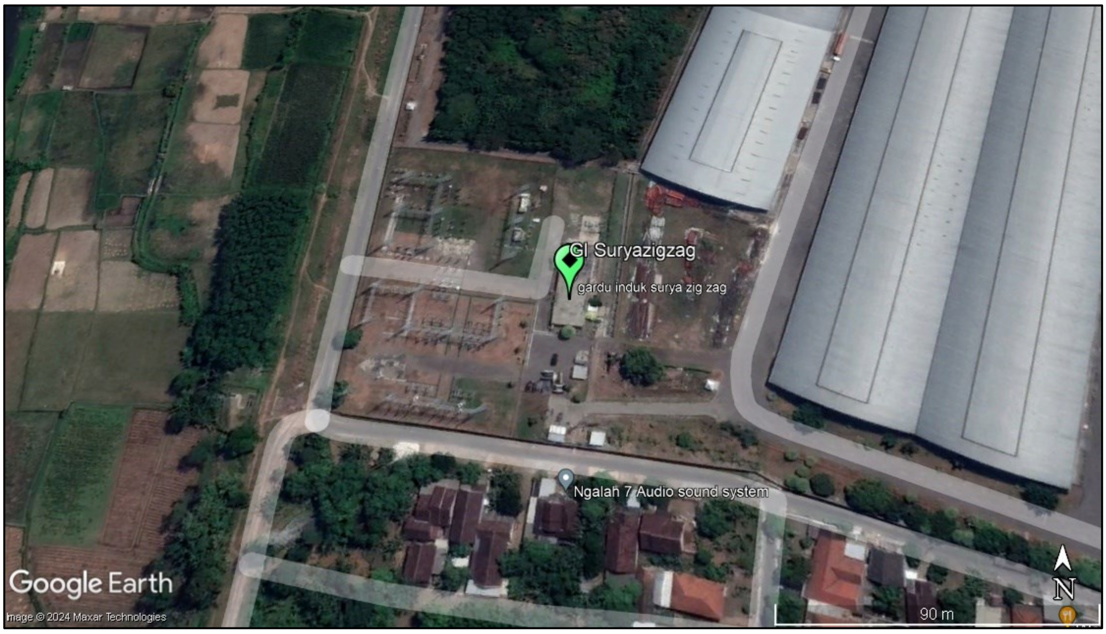

Figure 32. Location of the Surya Zig Zag 150 kV PLN substation. Source: Google Maps.

2.7.2 Schematic design transmission and distribution network

In Figure 33, the schematic design of the transmission and distribution network is illustrated. The 48 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 maximum10 wind turbines, the generated electricity is distributed to one of the five 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 Surya Zig Zag substation.

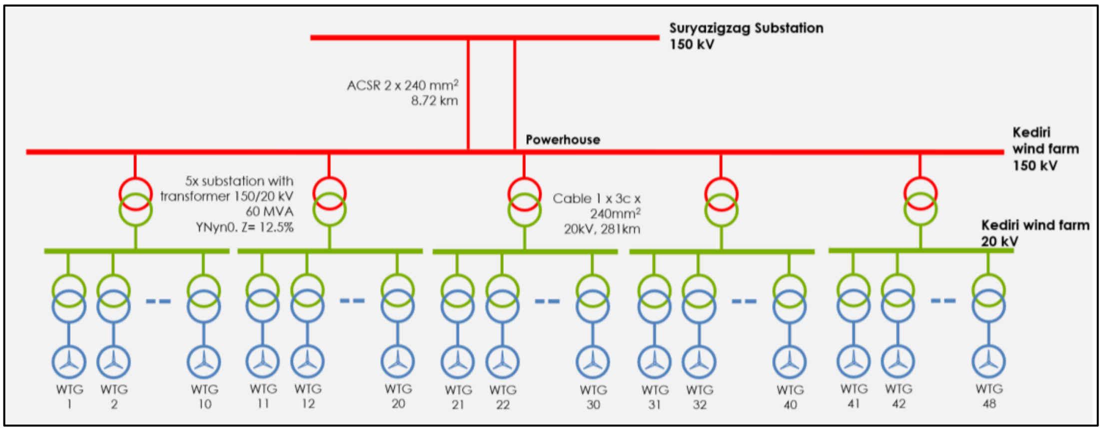

Figure 33. A schematic design of the transmission and distribution network at the envisioned Kediri wind farm

The overhead transmission line between the powerhouse and the PLN substation is assumed to be a straight line between both locations, covering 9 km as visualized in Figure 34. A total of 25 towers are planned with an intermediating distance between the towers of 340-450 m.

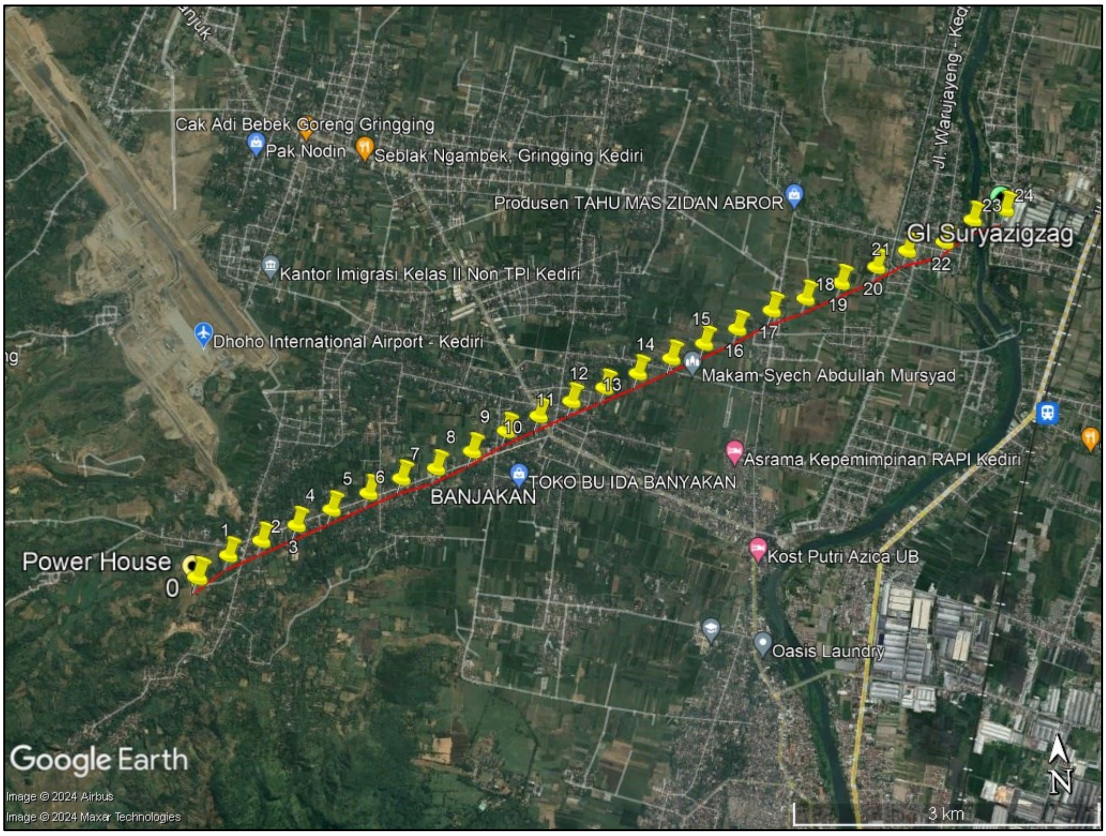

Figure 34. A schematic representation of the position of overhead transmission line between the powerhouse and the Surya Zig Zag substation

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 Kediri 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 35 shows the resulting climatology at the locations of the WTGs. The modeled long-term wind speed, which is averaged over all 48 WTGs at the planned hub height of 140 m, is 6.3 m/s. It must be noted that the mean wind speed in the Global Wind Atlas (GWA) is higher (6.8 m/s). Nevertheless, verification of the numerical models through measurements is essential, and here, the more intricate LES model is employed for further analysis.

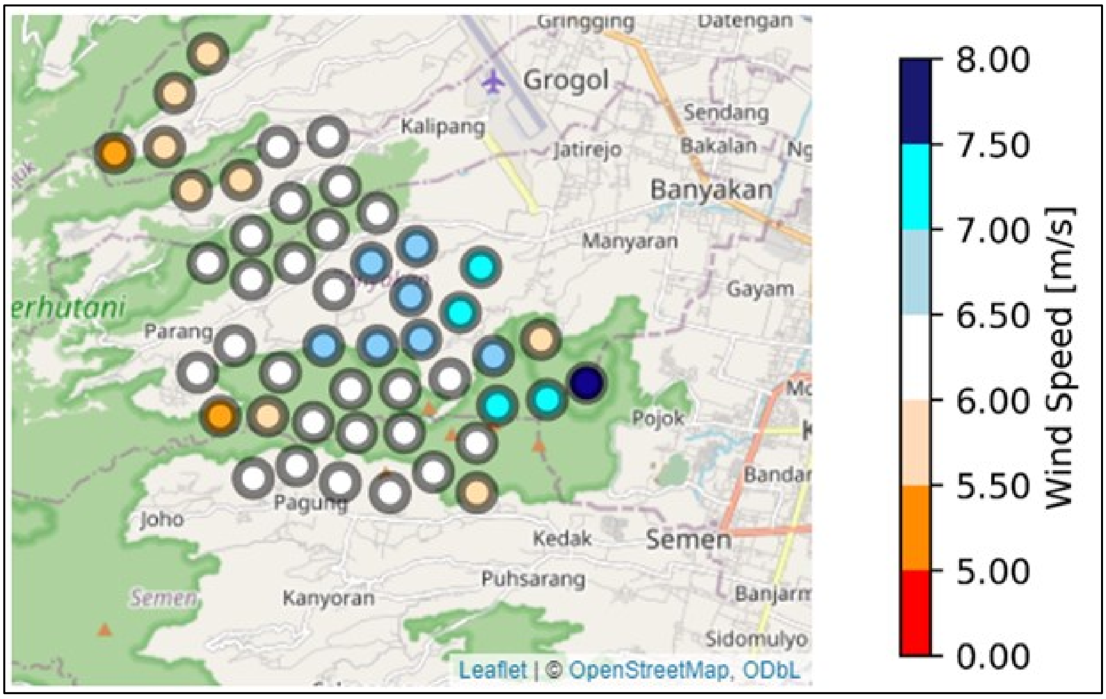

Figure 35. Long-term average wind speed results with the ASPIRE model at a height of 140 m at the turbine locations. The black-bordered circles represent the wind turbines, whereas the colors within the circle indicate the respective long-term average wind speed.

For some of the turbine locations, the modelled wind speed is below the threshold of 6 m/s. Considering the prevailing southern wind direction, it is likely that the six northwestern turbine locations have the lowest wind speeds. Therefore, these locations might be left out during the next optimization round. In future research, some of the southern turbine positions might also be optimized.

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.

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 [%]	8.6%	The wake effect is the aggregated influence on the energy production of the wind farm, which results from the changes in wind speed caused by the downwind impact of the wind turbines on each other. The wake losses are modelled using the standard NO Jensen (RISØ/EMD) model (PARK2 – 2018 version) in windPRO, resulting in an overall wake loss of 8.6%.
	Blockage losses [%]	0.0%	Wind farms do not only interact with downstream wind speeds (i.e. the wake effect), but also interact with decreased upstream wind speeds. This upstream wind speed reduction is called the blockage effect. The Self Similar model by Forsting (2016)[18] with linear parametrization is used to calculate blockage. 0% blockage is expected for the layout.
Availability	Non-availability [%]	4.0%	This production loss concerns the periods of a wind turbine that it is not in operation due to maintenance, malfunctioning and re-orientation of the nacelle. For onshore wind farms with more than 5 WTGs, 4.0% loss is considered.
	Balance of Plant [%]	0.1%	Balance of Plant losses occur due to the unavailability of the transformer station or access roads and therefore hinder normal wind farm operation.
	Grid downtime [%]	0.5%	Grid downtime losses are caused by grid non-availability from grid operator.
Performance	Power curve losses [%]	2.0%	Performance losses are the result of sub-optimal operation of the wind turbine. This occurs when wind turbines are operational outside the design conditions of the power curve. A conservative 2.0% performance loss is assumed since no site-specific power curve is available.
	High wind hysteresis [%]	0.5%	At the cut-out wind speed, wind turbines are switched-off due to safety precautions. The calculation model assumes that the wind turbines are fully operational until cut-out wind speed and are turned off from exactly that point. In reality, if the wind speed fluctuates around the cut-out wind speed, the wind turbine will shut down until the wind speed is below the re-cut in wind speed. A loss of 0.5% is assumed.

[18] 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
	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.
	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.

Category	Types of energy loss	Amount	Explanation
	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 on 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 [%]		**20.5%**	The accumulation of all of the above-mentioned losses, including wake losses. Based on 1-(1-loss A)*(1-loss B)*(1-loss C)*…etc.

2.8.2 Energy yield including uncertainties

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

Here we assume a conservative uncertainty to be 20%, since the calculations are purely based on numerical models and no measurements have been performed on-site at this stage. The resulting P90 value is given in
Table 9.

Table 9. Energy yield for all 48 WTGs at the Kediri wind farm

Parameter [Unit]	Amount
Number of new WTGs	48
Rated Power per WTG [MW]	4.0
Total rated Power [MW]	192.0
Rotor diameter [m]	~170
Hub height [m]	140
Air density [kg/m3]	0.986
Wind speed [m/s]	6.3
Gross result [MWh/yr]	652,994
Gross results including wake effects [MWh/yr]	603,366
P50 [MWh/yr] [19]	**519,135**
P90 (25 yr) [MWh/yr]	**386,075**
P50 [hrs/yr]	2,704
P90 (25 yr) [hrs/yr]	2,011

2.8.3 Power output variation

In Subsection 2.8.2, we have provided an estimate of the P50 annual production, equal to 519,135 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.

Figure 36 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.

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

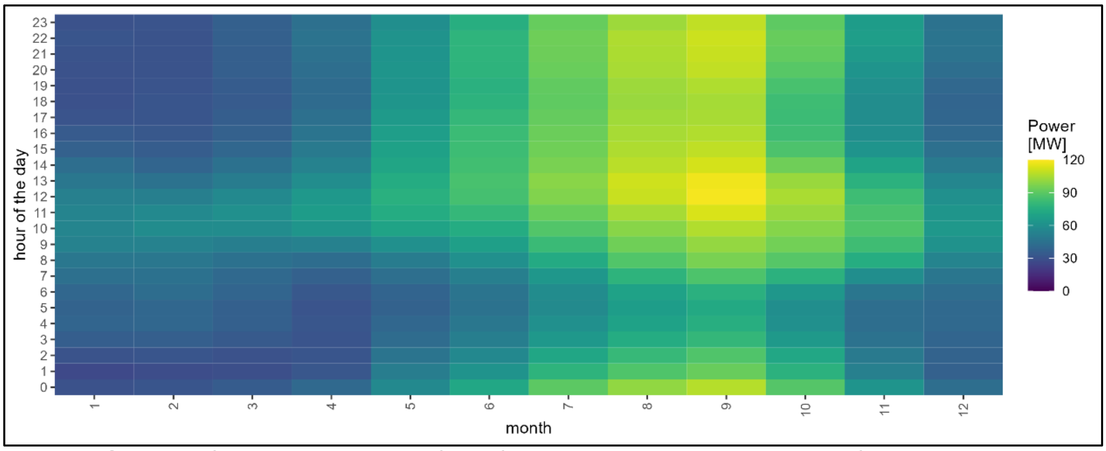

Figure 36. Overview of the monthly variation of wind farm average power output per hour of the day based on the P50 values from Subsection 2.8.2 in combination with the monthly and hourly variation in wind speed from EMD-WRF

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 (7 met masts for 1 year)

- Land acquisition, assuming IDR 200,000 /m^2 + 5% tax for low-quality soils, IDR 520,000 /m^2 + 5% for moderate fertile areas, to be used for:
    - 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 Kediri wind farm.

Main component	Quantity
Nacelle incl. generator (4 MW)	48 pcs
Blade (85 m)	144 pcs
Tower segments (total 140 m height)	288 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 Surabaya 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[20];
- The cost includes transport, crane rental, installation, and commissioning.

Civil works

The quantities which are relevant for the civil works necessary for the installation of 48 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	59 km
	Upgrading existing road	11 km
Strengthening bridges (incl. design, materials, transport, labor)	Concrete bridge strengthening	5 bridges

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

Main component	Sub-component	Quantity
New bridges	Two new concrete bridges (15 m in length) will have to be constructed on the southern access road.	2 bridges
Foundations (incl. design, materials, transport, labor)	Anchors (72 per foundation)	3,456 pcs
	Anchor cages	48 pcs
	Concrete (230 m^3 per foundation)	11,040 m^3
	Steel (35 tons per foundation)	1,680 tons
Crane hardstands (incl. design, materials, transport, labor)	Crane hardstands (50 x 100 m) using gravel	48 hardstands

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

- Civil works are including design, materials, transport, and labor;
- 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	25 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	48 pcs
	LV switchgear	1 pc
	DC Supplies	1 pc
	Lightning protection	1 pc
	2x3C 300 mm cable	567 m
	Transformers 20 kV (5 MVA)	48 pcs
	Switchgear	48 pcs

Main component	Sub-component	Quantity
Wind farm electrical works (between the powerhouse, substations, and wind turbines)	MVAC Cable (1 x 3c x 240) 50 and 300 meters	281 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 (five for the entire wind farm)	Transformer 150/20 kV 30 MVA	5 pcs
	Neutral Grounding Resistor	5 pcs
	Switchyard	1 pc
	In/outgoing bays, coupler, busbars, Panel RCP	5 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.
- No compensation for the use of forest required
- 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 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[21]) and to the other 7 locations.

Table 13. Cost assumptions per cost component.

Cost component	Baseline cost including VAT	Comment	Cost range
Preparation works	USD 4,615,000	DEVEX: Prior to Financial Close	90% - baseline -120%
Project management	USD 13,316,000	DEVEX: Until CoD	Baseline
Wind turbines	USD 133,790,000	CAPEX: Including transport and installation	90% - baseline -120%
Civil works: foundations	USD 19,234,000	CAPEX	80% - baseline -150%
Civil works: roads	USD 23,712,000	CAPEX	80% - baseline -150%
Civil works: crane hardstands	USD 7,140,000	CAPEX	80% - baseline -150%
Electrical works	USD 44,600,000	CAPEX	90% - baseline -120%
Land acquisition	USD 39,471,000	CAPEX	90% - baseline -150%
Risk contingencies	USD 21,306,000	DEVEX + CAPEX	Baseline
Lower bound total investment cost (DEVEX + CAPEX)	**USD 275,730,000**	**Investment cost per MW: USD 1,436,000**	
Baseline total investment cost (DEVEX + CAPEX)	**USD 307,995,000**	**Investment cost per MW: USD 1,604,000**	
Upper bound total investment cost (DEVEX + CAPEX)	**USD 389,374,000**	**Investment cost per MW: USD 2,028,000**	
Baseline operational expenditure (OPEX)	**USD 5,602,000 / year**	**Operational cost per MW / year: USD 29,000**	

2.9.3 Financial parameters

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

- The wind farm has a design lifetime of 25 years;
- A depreciation period of 25 years;
- The construction starts in the year 2028;

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

- 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 1.0 for the Jamali grid) = USD cent 9.54 / 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	9.96%	8.09%	4.61%
Average Debt Service Coverage Ratio (DSCR) at P90	0.83	0.76	0.61
Net profit at P50 over 25 years	USD 168,362,000	USD 134,719,000	USD 55,086,000

3 Conclusion and Recommendations

Based on the conducted analysis, it is concluded that the overall techno-economic viability of a wind farm in the Kediri region requires improvement. The main cause for this result is the lower wind speeds than expected at specific wind turbine locations. Although the initial wind resource assessment only included areas with annual average wind speeds above 6 m/s, during the wind modelling stage, the long-term wind speed at ten wind turbine locations turned out to be below this number (see Figure 35). This is caused by the effect of the site's topography on the wind characteristics, which is to a lesser extent notable when creating a wind speed map based on Global Wind Atlas.

Based on the wind modelling, it seems that less promising wind speeds are found on the northwestern corner and western part of the envisioned wind farm. Therefore, we recommend reconsidering the site's layout during a follow up study. The business case could be improved by potentially excluding a couple of wind turbine locations in the western area for future development, and validating the wind speed (by wind measurements). Exclusion of the few wind turbine locations could still lead to a wind farm size of approximately 120-150 MW.

Aside from the lack of wind resources at several wind turbine locations, the envisioned wind farm entails other 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. Hence, we recommend placing met masts for data gathering for at least one year (see Figure 37). 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. Meanwhile, the yellow icons show the global positioning of recommended met mast locations.

  The turbine layout starts at the foot of the slope around 140 m and goes up to 500 m. The top of the volcano is around 2,300 m. In order to capture the average site conditions with met mast, we recommend installing at least 7 met masts. The met masts are spread over the site in order to capture the spatial variability. In the southeastern part of the WTG area, there is a small hill. On the volcano slope and hill, it is recommended to additionally measure with an ultrasonic 3D anemometer. This is necessary because the turbines will most likely experience up- and downdrafts on the ridge. Using the ultrasonic 3D anemometer, the horizontal velocity and vertical velocity of wind will be measured. The ultrasonic 3D anemometer should also be considered in the northern area.

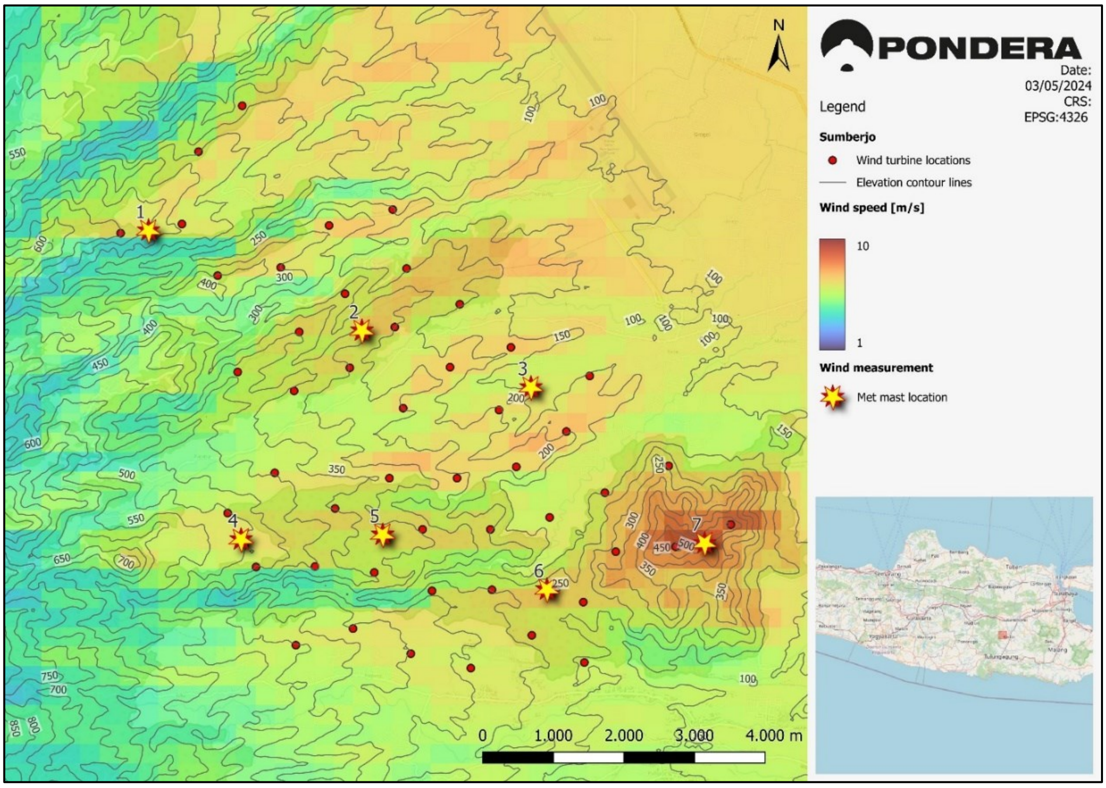

Figure 37. Recommended met mast and LIDAR locations.

- **Land use and permitting:** As can be derived from Figure 29 and Subsection 2.2.5, the wind farm is planned in roughly a 70/30 split between forest/shrubs area and crops area. For the former area, it will be mandatory for the future developer to obtain specific approvals and permits from the authorities; whereas for the latter area, a deal will need to be struck with the landowner to either acquire or lease the land. Considering these required actions, it is also important for the developer to assess the land use / ownership in greater detail early in the development process. The developer is recommended 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 Surabaya is the most suitable starting point for the transport over land.. To ensure that the port in Surabaya 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. For subsequent feasibility study, we recommended several aspects to be further analyzed. Firstly, accurate heights between road surface and bridges on toll roads must be inquired or measured. The height of the lowest bridge may be a limiting factor of the diameter used for the base of the turbine tower. Secondly, planning of toll road construction from the existing toll road (Surabaya-Solo) to Kediri shall be further investigated. Finally, possible usage of the road surrounding the airport (as this might be in private hands) shall be scrutinized.

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

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

- **Environment:** Although the wind farm location is not a densely populated area, there will be visual impact on the area because of the use of wind turbines with a tip height of 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. Furthermore, the envisioned wind farm is located 3 km from Dhoho Airport. Given this proximity, a thorough check with the airport authority will be needed on whether flight navigation at the airport could be disrupted by the presence of the envisioned wind farm.

- **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. Several animal and plant species were observed in the area that are categorized in the IUCN global red list category. It is likely that the wind farm development will have an effect on biodiversity. Consequently, it is advised that during the feasibility study, a biodiversity baseline study, and risk assessment and mitigation measures are conducted as part of the Environmental and Social Impact Assessment.

- **Grid connection and PPA:** The wind farm is designed to be connected to the PLN grid. This assumes that the grid can integrate 192 MW of wind energy (with variable output), and that the substation in Surya Zig Zag 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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