REPORT

Wind Energy Development Prospectus:
80 MW Project in Gunung Kidul, DI Yogyakarta

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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Table of Content

List of Figures

List of Tables

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 Gunung Kidul 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

Section 2.6: Biodiversity, socio-economic and environmental conditions

Section 2.7: Transmission network design

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

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

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

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

2 Analysis of Gunung Kidul Wind Farm, DI Yogyakarta – 80 MW

2.1 Introduction of the wind farm location

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

2.1.1 Geographic location

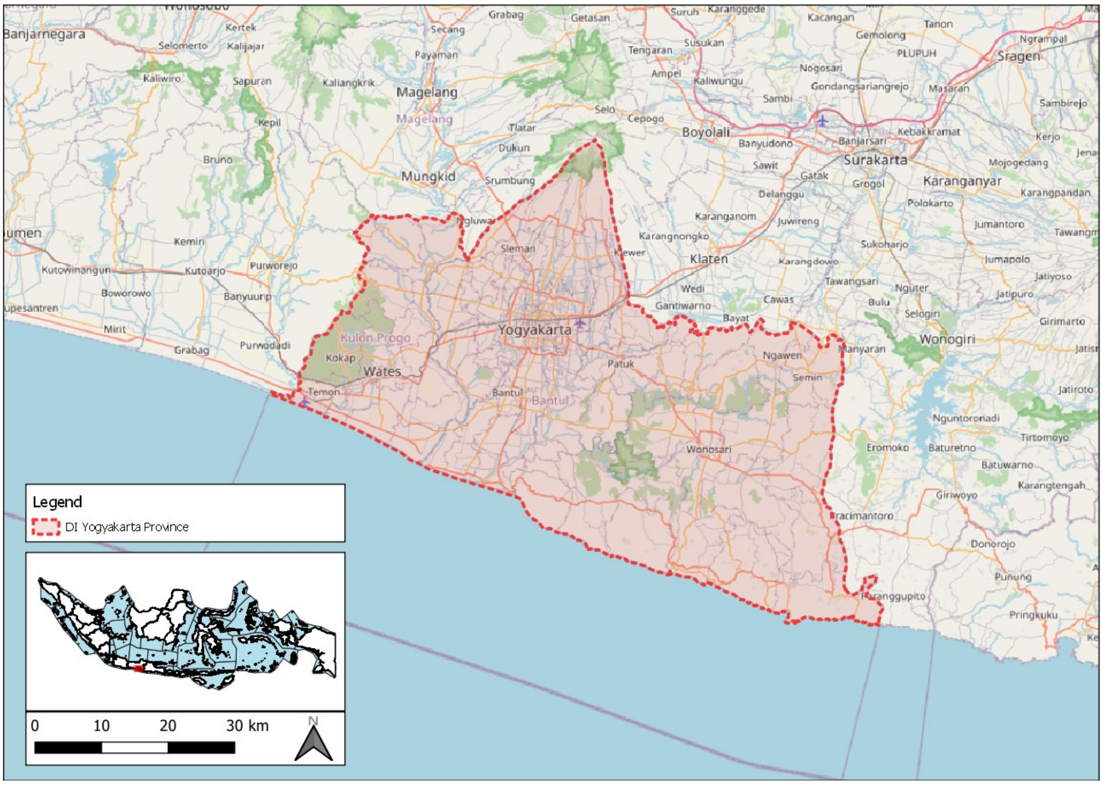

Figure 1. A map of DI Yogyakarta province in which the envisioned Gunung Kidul wind farm area is located.

As shown in Figure 1, DI Yogyakarta is a province situated in the southern coast of Java Island, bordering the Indian Ocean. There is only one neighboring province of DI Yogyakarta, namely, Central Java. Covering a relatively small area (compared to the other assessed wind farms in Component 3) of 3,186 km^2, DI Yogyakarta is home to around 3.8 million people in 2022[1]. GDP per capita of this province is IDR 44.04 million, ranked 26th among all provinces in the country[2]. Furthermore, the province's economic growth is 5.07% 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://sulut.bps.go.id/indicator/12/958/1/jumlah-penduduk-menurut-provinsi-di-indonesia.html
[2] https://www.statista.com/statistics/1423411/indonesia-per-capita-gdp-at-current-prices-of-provinces/
[3] https://yogyakarta.bps.go.id/pressrelease/2024/02/05/1595/pertumbuhan-ekonomi-diy-triwulan-iv-2023.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

Like Aceh, DI Yogyakarta is also one of Indonesia's special regions although for different reasons. DI Yogyakarta was granted a special autonomy because the province is governed by the Sultanate of Yogyakarta. Since 2012, the Governor and Vice Governor position has been taken by the Sultan and the Duke, respectively.

Furthermore, the province is known for its ancient heritage in the form of buildings (e.g. temples and palaces) or other things (e.g. culture, food, and art). This makes DI Yogyakarta a popular destination for tourists. Besides tourism, other main economic activities in the province include (higher) education and agriculture/farming.

There is only one Industrial Estate in the province, i.e. Piyungan Industrial Estate[5], despite issues arising in recent years regarding its development[6]. Additionally, there is no 'large' new electricity consumer in the province listed in Appendix E of RUPTL PLN 2021-2030. Nonetheless, the grid in DI Yogyakarta is connected to the broad Java-Madura-Bali transmission network. Therefore, electricity generated in the province can be transmitted to elsewhere regions within the network. In the next subsection, the projected power demand levels of the province will be presented.

The considered wind farm location is located in Gunung Kidul Regency, in the southeast end of DI Yogyakarta.

2.1.2 Status in RUPTL PLN 2021-2030

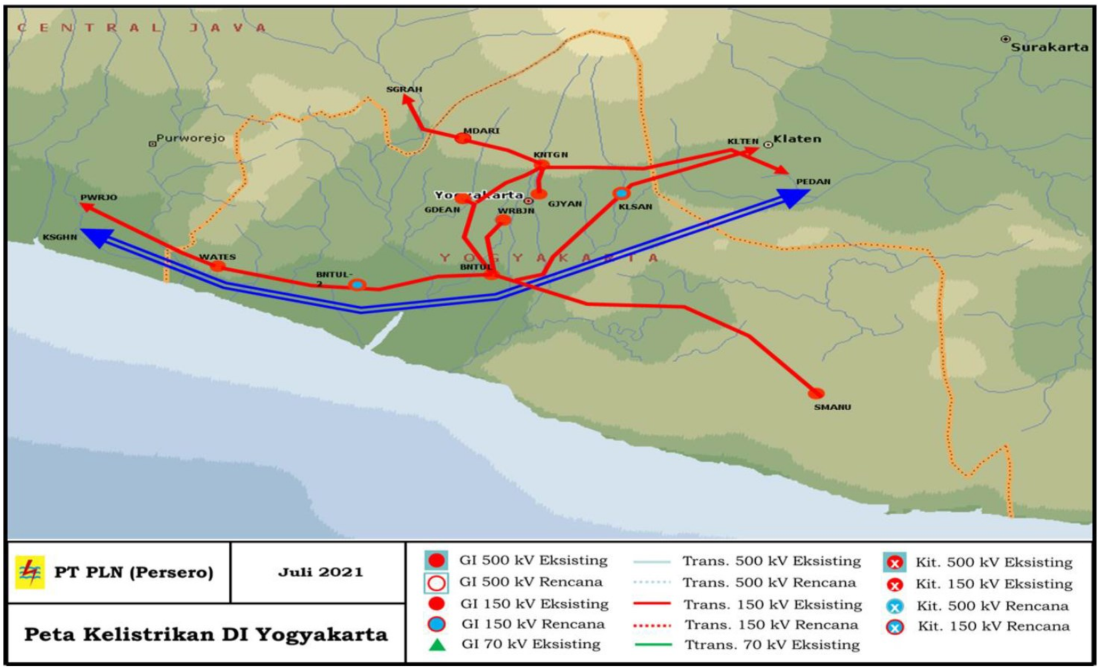

Figure 2. A map of DI Yogyakarta electricity system in RUPTL (Source: RUPTL PLN 2021-2030)

[5] https://regionalinvestment.bkpm.go.id/pir/kawasan-industri-kek/
[6] https://www.medcom.id/nasional/daerah/akW5JBqN-pengelolaan-kawasan-industri-piyungan-yogyakarta-bermasalah

Figure 2 portrays the electricity system of DI Yogyakarta. The system includes a 150 kV transmission lines connecting several substations in the province and the broader Java-Madura-Bali system. There is also a 500 kV transmission line crossing DI Yogyakarta and connecting with the broader system. According to RUPTL PLN 2021-2030, the peak load of this province in 2020 is 450 MW. Within the period of 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 annual demand growth rate will be 4.88%.

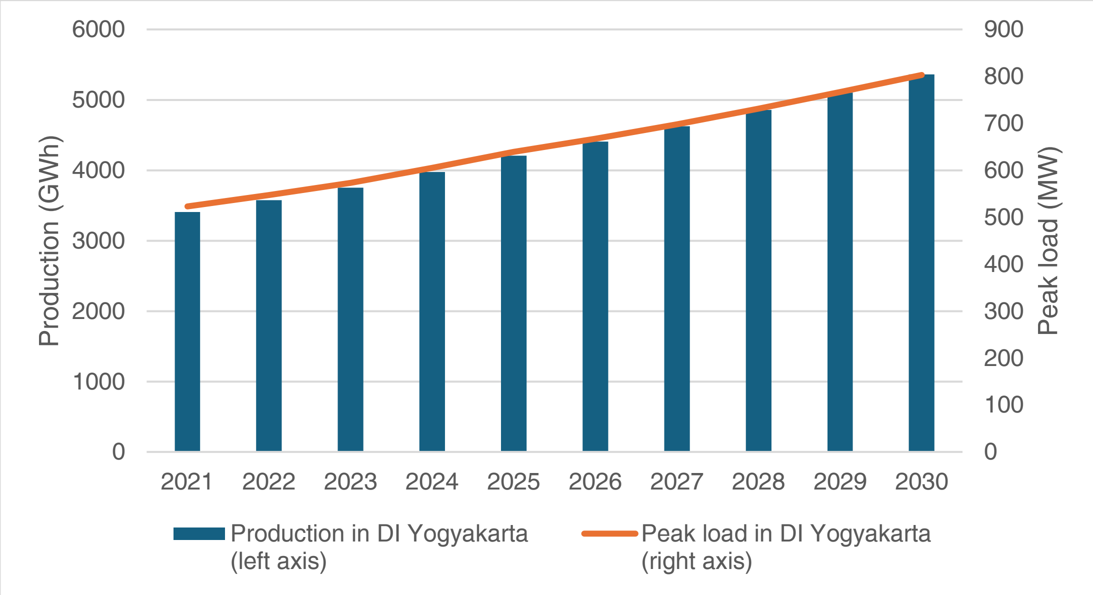

Figure 3. Projected electricity production and peak load in DI Yogyakarta (Source: RUPTL PLN 2021-2030)

According to the RUPTL, there is no plan to add more power plants in DI Yogyakarta in 2021-2030. Instead, the RUPTL lists two potential wind farms to be developed in the future: Gunung Kidul (10 MW) and Samas Bantul (50 MW). The former location is likely to overlap, in whole or in part, with the wind farm area being assessed in this prospectus.

2.1.3 Status of development

There was at least one developer active in Bantul, DI Yogyakarta. UPC Renewables Indonesia initiated their 50-MW wind farm development in Samas Beach, Bantul, before the development was said to be cancelled in 2019 due to technical reasons[7]. One of the issues was land acquisition, as the envisioned wind farm site is partly built on a piece of land owned by the Sultan[8].

In 2014, the Regency Government of Gunung Kidul cooperated with the Technology Assessment and Application Agency (*Badan Pengkajian dan Penerapan Teknologi*/BPPT) to develop a small-scale wind farm in Baron Techno Park. A few wind turbines were installed for research purposes[9]. There are, however, no further developments taking place afterwards.

[7] https://www.antaranews.com/berita/999364/proyek-pengembangan-pltb-pantai-selatan-bantul-tidak-berlanjut
[8] https://www.liputan6.com/bisnis/read/3080227/terkendala-pembebasan-lahan-proyek-pltb-samas-berhenti
[9] https://nasional.tempo.co/read/558192/gunung-kidul-siapkan-listrik-tenaga-angin

2.2 Wind resource availability and land use

2.2.1 Approach

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

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

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

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

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

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

2.2.2 Wind resource and characteristics

Figure 4 shows the initial search area (bounded by the purple-dash box) in DI Yogyakarta. 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 some scattered locations, which are separated at lengthy distances.

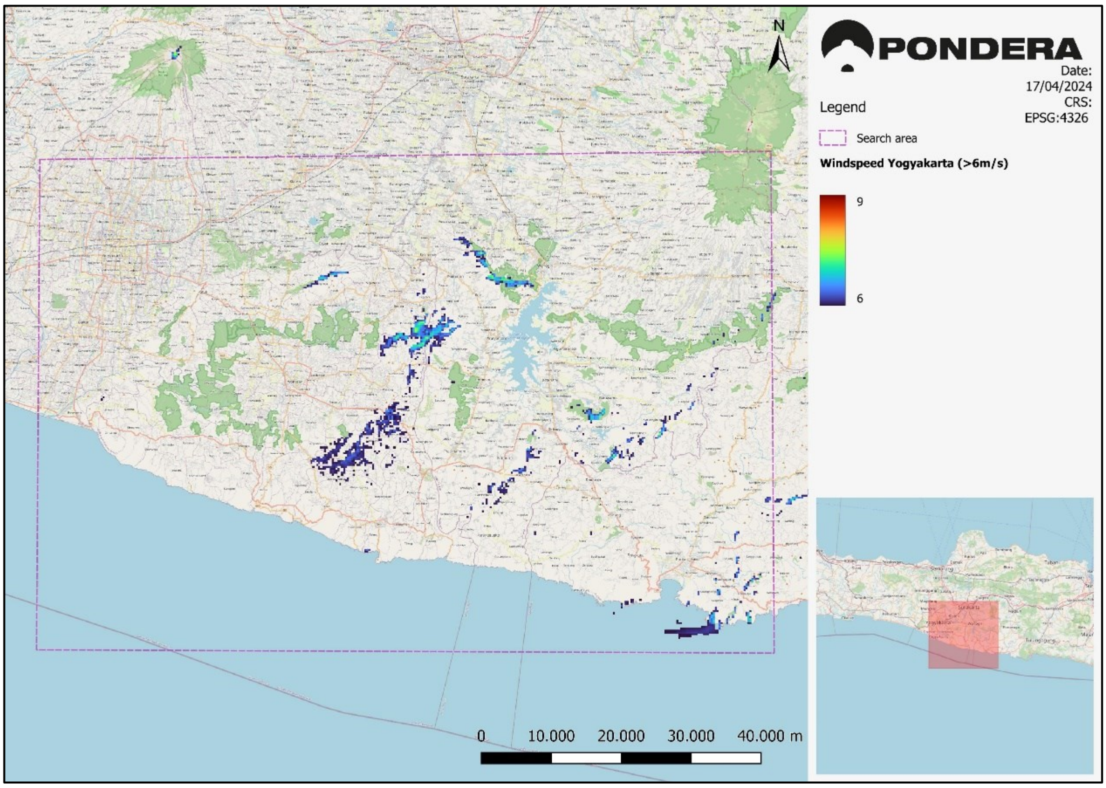

Figure 4. DI Yogyakarta search area with wind speed distribution. The purple-dash bounding box shows the full search area. The color bar indicates average wind speeds which are above 6 m/s at 100 m height according to the Global Wind Atlas (GWA) climatology.

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 5 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.

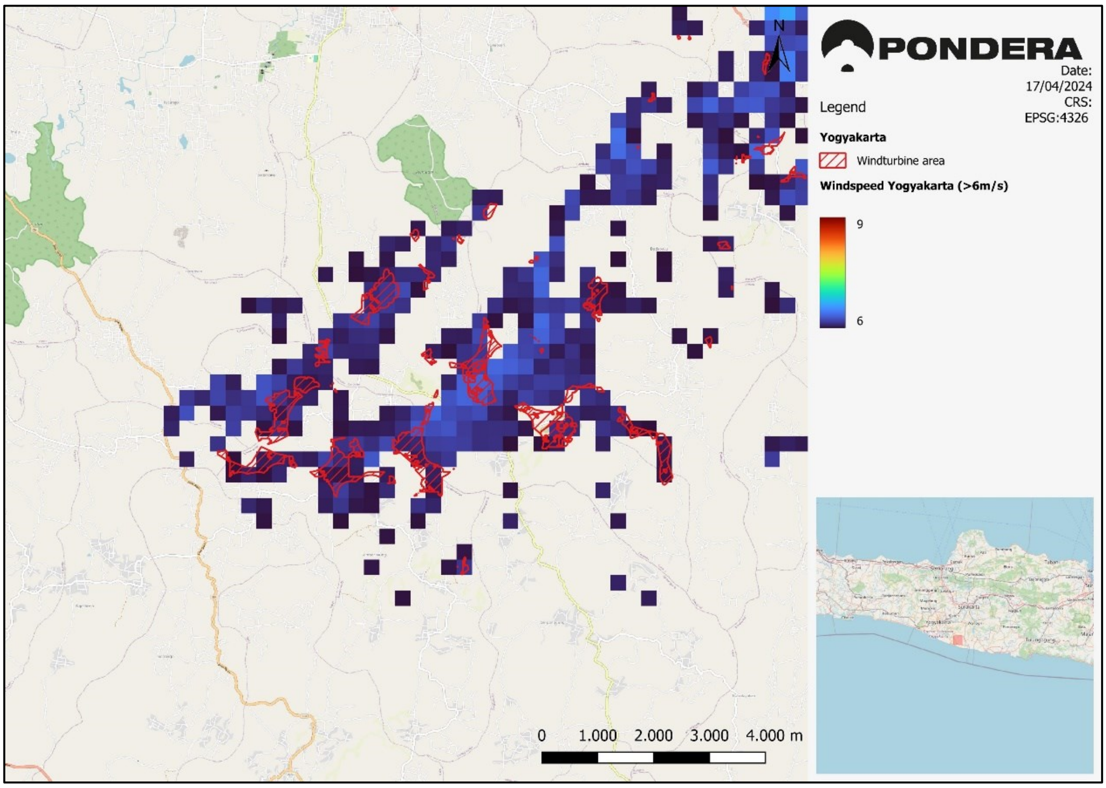

Figure 5. A zoomed-in look at the DI Yogyakarta search area, focusing in Gunung Kidul Regency, along with the wind speed distribution. The red, dashed polygons represent the final WTG-area which meets all the criteria. Average wind speeds above the threshold of 6 m/s at 100 m height according to GWA are shown.

Additionally, Figure 6 visualizes the long-term average wind direction distribution for the DI Yogyakarta area, particularly at Gunung Kidul Regency. As can be interpreted from this figure, the wind climate in the area primarily consists of wind from the southeastern direction.

In Figure 7, 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 southeastern 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. 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.

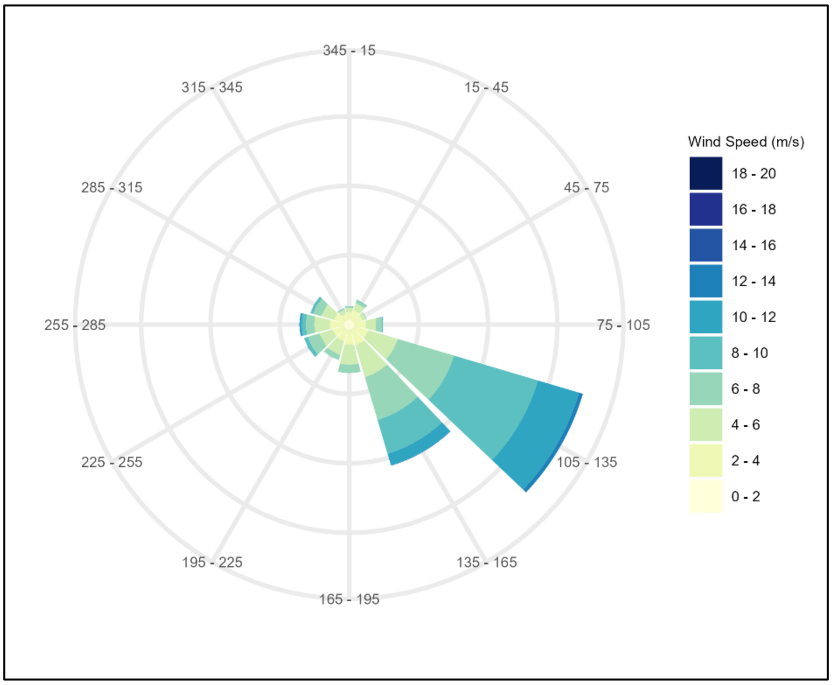

Figure 6. Wind rose diagram with wind directions and wind speed categories based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

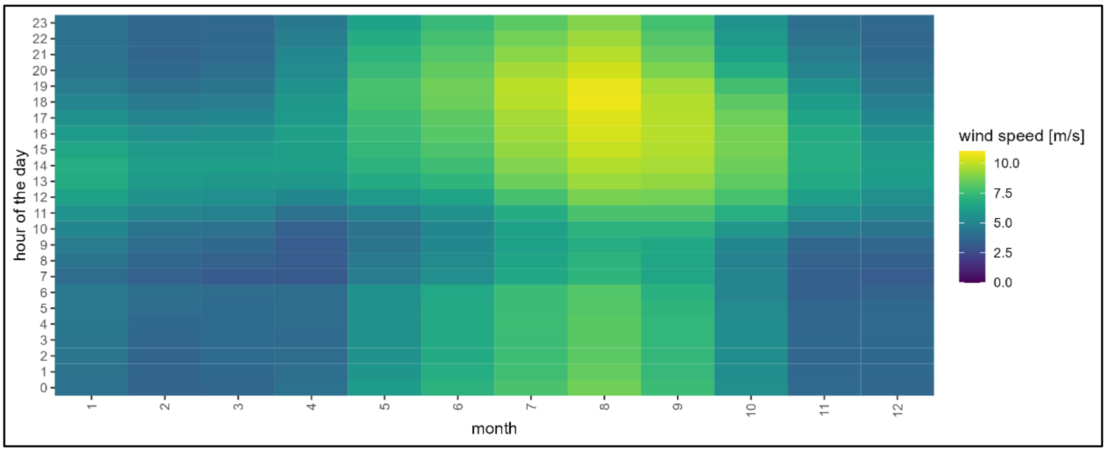

Figure 7. The wind speed distribution throughout the day, visualized per month of the year. Based on a 10-year climatology, including the 2004-2015 time series of hourly data. Source: EMD-WRF.

2.2.3 Topography

Figure 8 shows the topography of the search area in the Gunung Kidul 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.

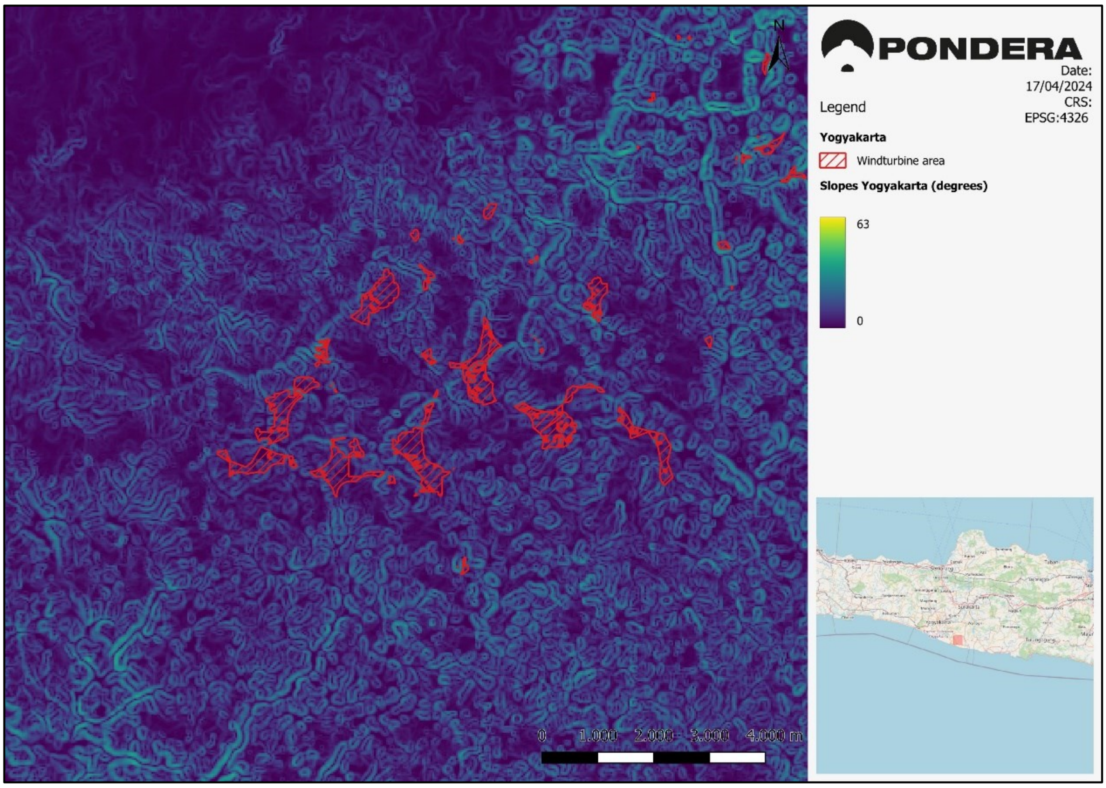

Figure 8. Topography of the Gunung Kidul WTG-area, showing the slope (in degrees; according to calculated based on FABDEM data) at the region.

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 9). 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 9.

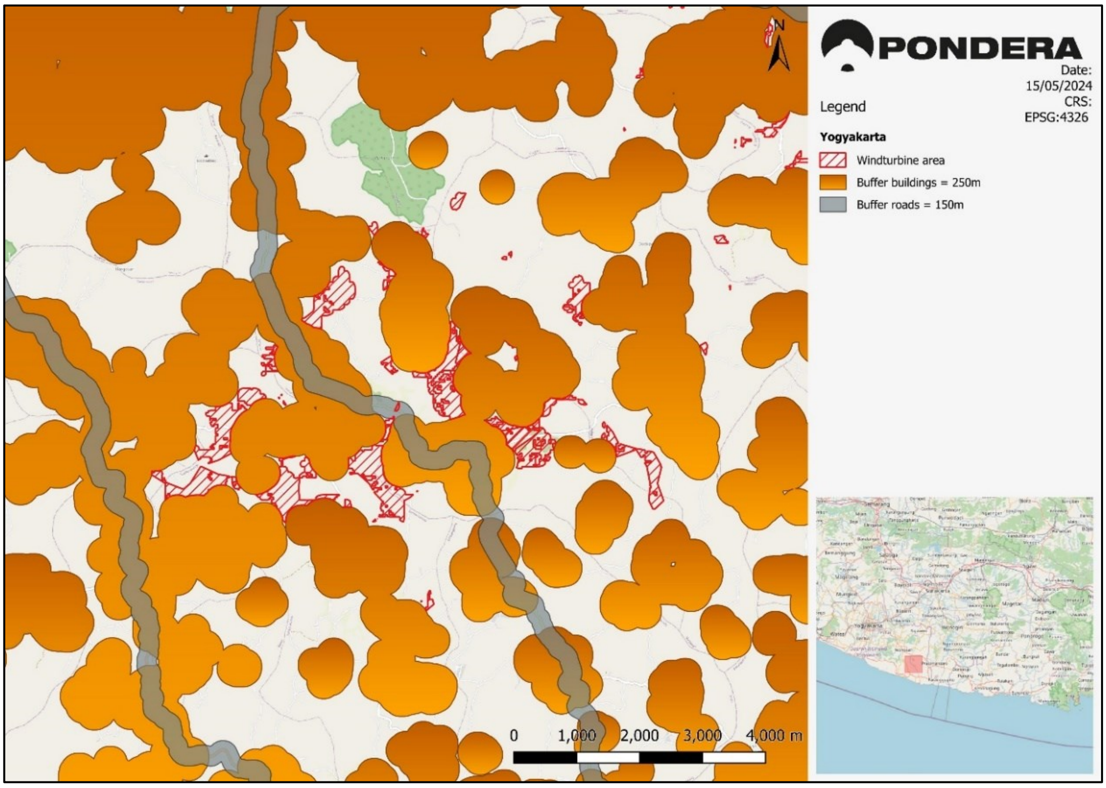

Figure 9. Exclusion zones at the Gunung Kidul area based on land use and residential areas. Source: ESRI and OSM.

2.2.5 Specific permitting requirements

Figure 10 shows the overlay between Gunung Kidul Regency Spatial Plan (*Rencana Tata Ruang Wilayah* or RTRW) 2010-2030 and the final WTG-area. According to the figure, the final WTG-area (continuous area with promising wind speed) is located in the following land use types:

1. Dryland Farming/Agricultural Area (*Kawasan Pertanian Lahan Kering*)
2. Residential Area (*Kawasan Permukiman*)

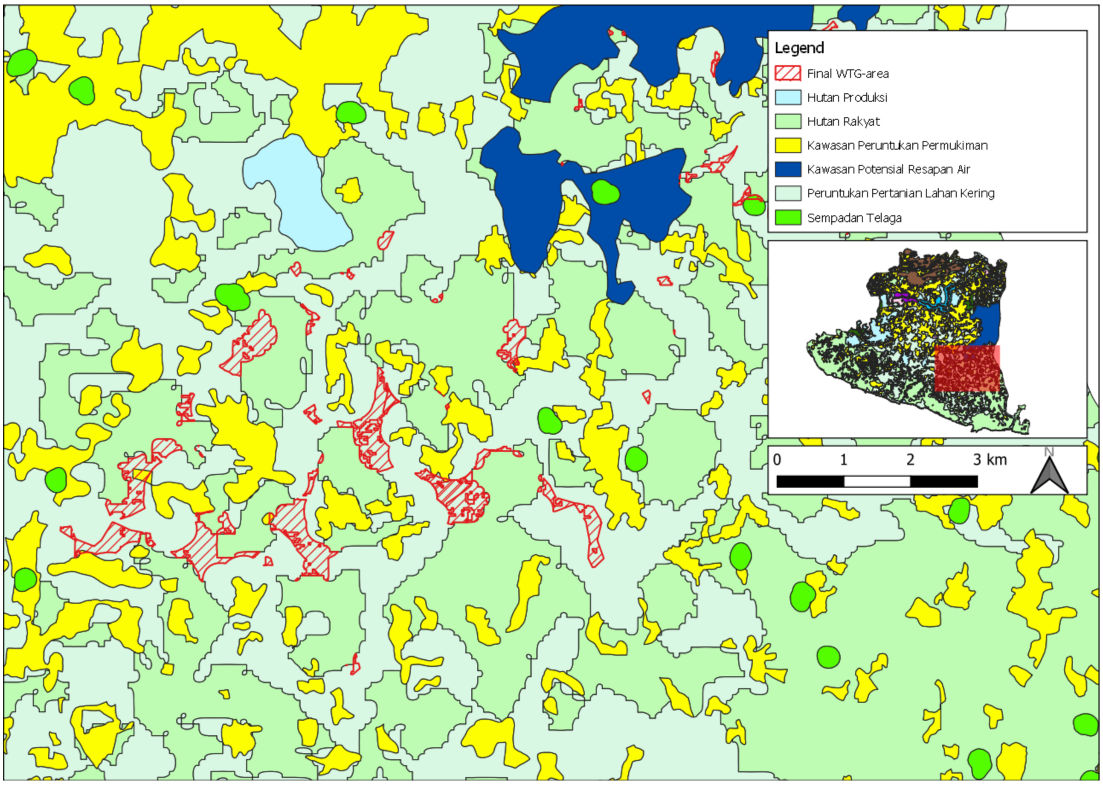

Figure 10. The map of spatial plan of Gunung Kidul Regency (RTRW 2010-2030) overlaid with the final WTG-area.

A majority of the final WTG-area is located in Dryland Farming/Agricultural Area. Such an area is usually owned by the local community. If the area is not part of the Sustainable Food Agriculture Area (*Kawasan Pertanian Pangan Berkelanjutan*/KPPB), then the Dryland Farming/Agricultural 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[10]. Meanwhile, a very small fraction of the final WTG-area intersects with Residential Area. To facilitate wind farm development in this area, then an agreement shall be made with the landowner either to purchase or to lease the land. Costs related to the land acquisition for the wind farm have been taken into account in the business calculation made in Section 2.9.

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

It is important to note that the obtained RTRW is for the year 2010-2030. 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 appropriate agency in Gunung Kidul is required. If there is already a new RTRW Regional Regulation, the RTRW used in this report is no longer valid. However, if the RTRW has not yet been revised or is still being revised, then the analyzed 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 11. This area meets all the criteria as visualized in the previous figures.

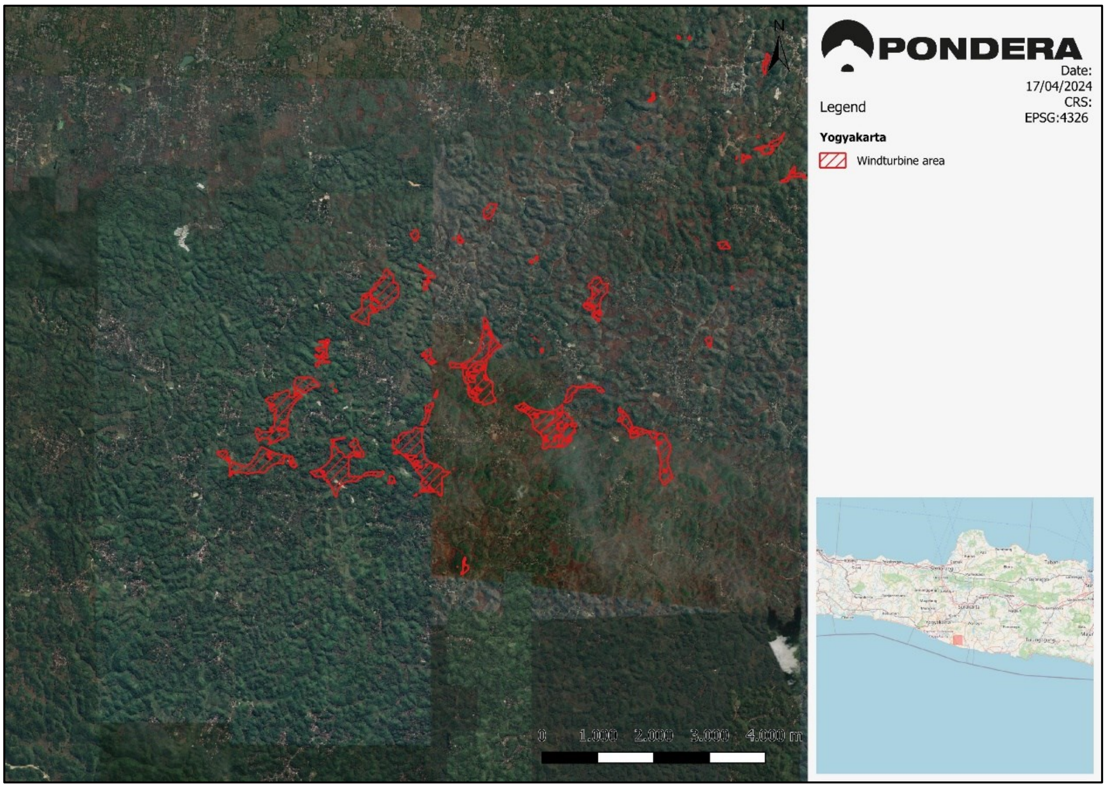

Figure 11. Final WTG-area based on the restriction criteria. Source: Google Satellite Images.

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.

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.

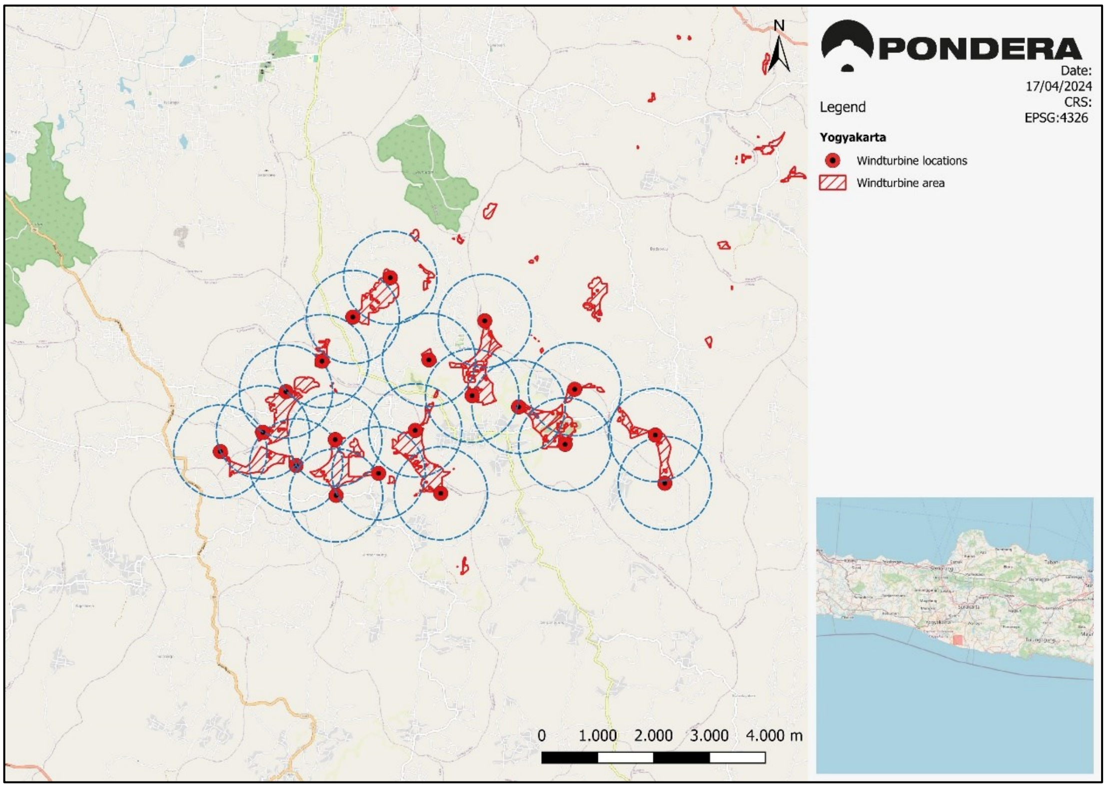

Figure 12. Preliminary wind farm layout at the final WTG-area.

Figure 12 displays an overview of the wind turbine locations in the final WTG-area. A total of 20 wind turbines were positioned into the area, amounting to an envisioned total installed capacity of 80 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 13). 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 13. 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

Semarang or Surabaya – Site

Accessibility of the south coast of Java is limited, both sea and land. Only a few small fishing ports are situated on a mostly rocky coast. The shoreline is not protected from waves from the open ocean. Roads on the south coast are mostly local to regional, and wind through the hills and mountains. Long distance transport of goods is mostly done via the northern part of the island. All transport via sea in this region happens via the major ports of Semarang (Port of Tanjung Emas; see Figure 14) and Surabaya (Port of Tanjung Perak; see Figure 15) on the north coast, in the calmer Java Sea. Both ports are well connected by highways/toll roads. In Semarang, the ring road is connected to the highway/toll road. In Surabaya, the entry point of the highway is located right at the entrance of the port.

While the Port of Semarang is closer (~170 vs ~360 km), the Port of Surabaya might be used as well. Other envisioned wind farms on eastern Java in this study (Ponorogo, Kediri, and Probolinggo) lie closer to Surabaya than to Semarang. When one or more of those are constructed, transport for all sites via one access point may have advantages (i.e. contacts with port and authorities, contracts, port investigation, temporary storage which can be reused, etc.).

From both Semarang and Surabaya, a toll road system is finished until Solo/Surakarta. The toll road to Yogyakarta is in the process of being built and/or almost finished in some parts. The section Solo-Klaten was opened in April 2024, whereas the section until the Prambanan exit and Purwomartani exit is expected to open later this year or next year.

Figure 14. Port of Semarang with entry point of the ring road nearby the port.

Figure 15. Port of Surabaya. Entry/exit road of 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.

Up to this point, no road upgrades are expected as the toll roads are wide in all sections (2 lanes + emergency shoulder). However, a limiting factor may be the height of the numerous bridges over the toll roads. 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 present. 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.

Based on a rather rudimentary method (see Figure 16), 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 16. 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.

From the Purwomartani exit, the proposed route is south via road 086 (Jl. Prambanan) to the national road 3 (Jl. Wonosari) to Gunung Kidul/Wonosari. In the southeast of Yogyakarta, the road will ascend a plateau. The road features two hairpins in this ascent.

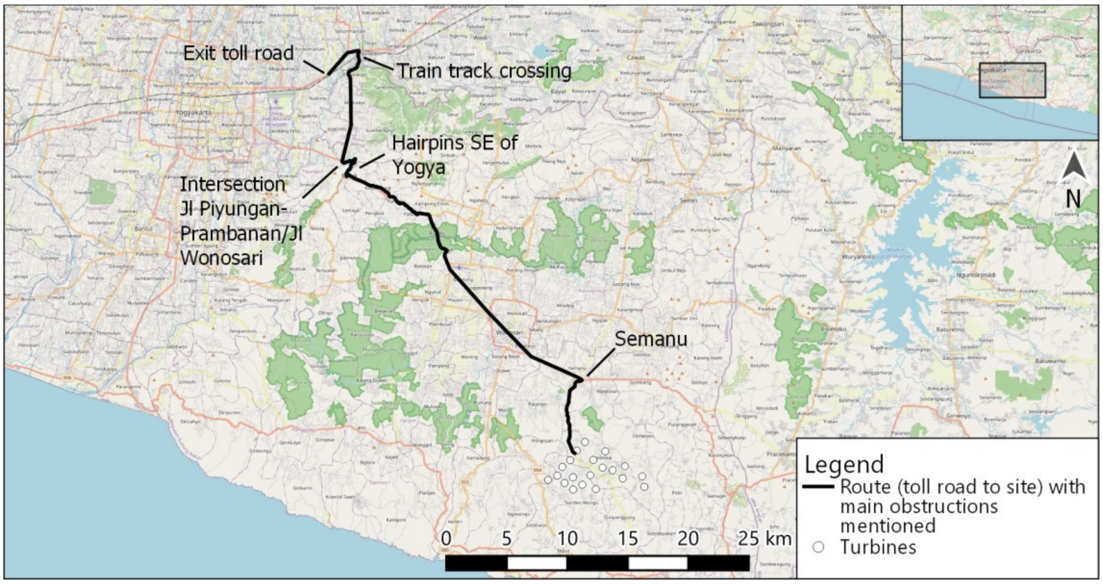

Figure 17. Route from the toll road to site. The toll road from Semarang and Surabaya are not shown as this is assumed to be wide enough and not problematic. Parts of the toll road from Klaten to Yogyakarta are still under construction and expected to be operational in 2025.

This road crosses several bridges and a railroad, which has been electrified. Signs indicate that the powerlines hang at an elevation of 4.6 m, as can be seen in Figure 18. Careful planning with KAI (Indonesian Railway Company) is necessary when cables need to be removed temporarily.

Figure 18. Railroad crossing on Jl. Prambanan.

The intersection from road 086 (Jl. Piyungan - Prambanan) to national route 3 (Jl. Wonosari) is a 90-degree turn on an intersection, as visualized in Figure 19. On the opposite side of the intersection is a barren piece of land (100 x 40 to 50 m) with some temporary buildings (such as a police post) which could theoretically be used for maneuvering.

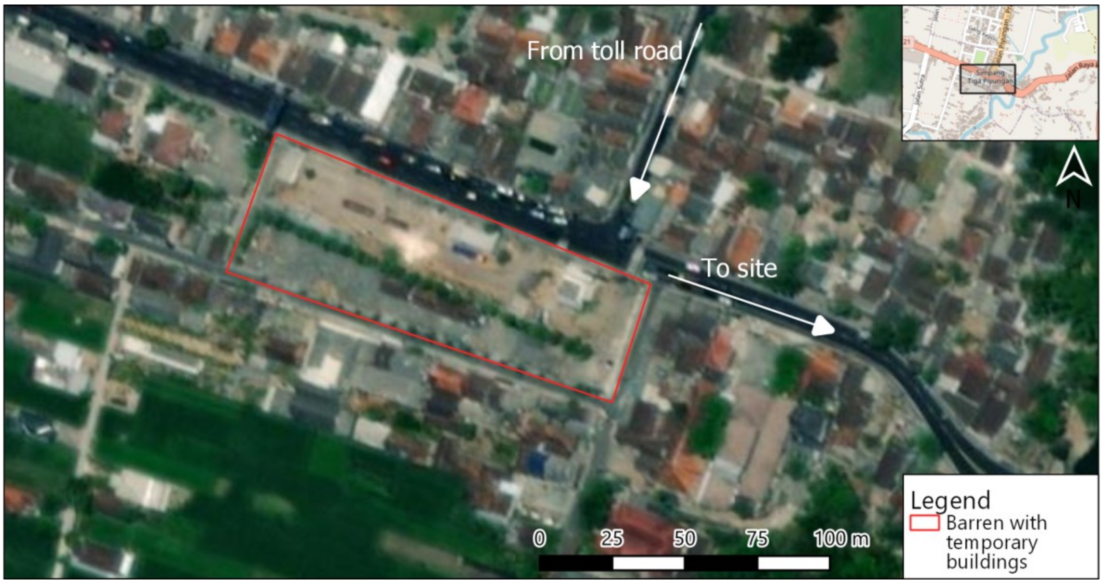

Figure 19. Junction of Jl. Piyungan-Prambanan/Jl. Wonosari.

On the main road to Gunung Kidul, a few hairpin-turns lead up a steep hill. The hairpins are narrow and might need some widening or at least the removal of trees to create more space for maneuvering. Two of these hairpins are displayed in Figure 20 and Figure 21.

Figure 20. Hairpin 1 on national road 3, in the southeast of Yogyakarta.

Figure 21. Hairpin 2 on national road 3, in the southeast of Yogyakarta. Both hairpins are on the same ascend approximately 1.5 km from each other.

For all necessary changes to the railroad crossing, the junction at Jl. Piyungan-Prambanan/Jl. Wonosari and possible improvements for the hairpins. The assumed improvement costs are included in the business case calculations in Subsection 2.9.

Bridges

The road from Yogyakarta (toll road) to the site crosses 21 bridges and 3 large culverts or very small bridges. These range from small concrete (10 m) to larger concrete bridges (60 m). In some cases, a steel bridge and a concrete bridge are present next to each other. Examples of these bridges are shown in Figure 22.

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

Semanu Town

From the main road, a smaller road from Semanu leads to the project site. The existing road runs through the center of this town and its market. Large components probably cannot be transported through the town in its present configuration.

Figure 23 shows a possible solution how the center and the market can be circumnavigated without the removal of buildings. A temporary road on the western side of town is less feasible, as a river runs through the western part of the town, and thus, another bridge will have to be constructed.

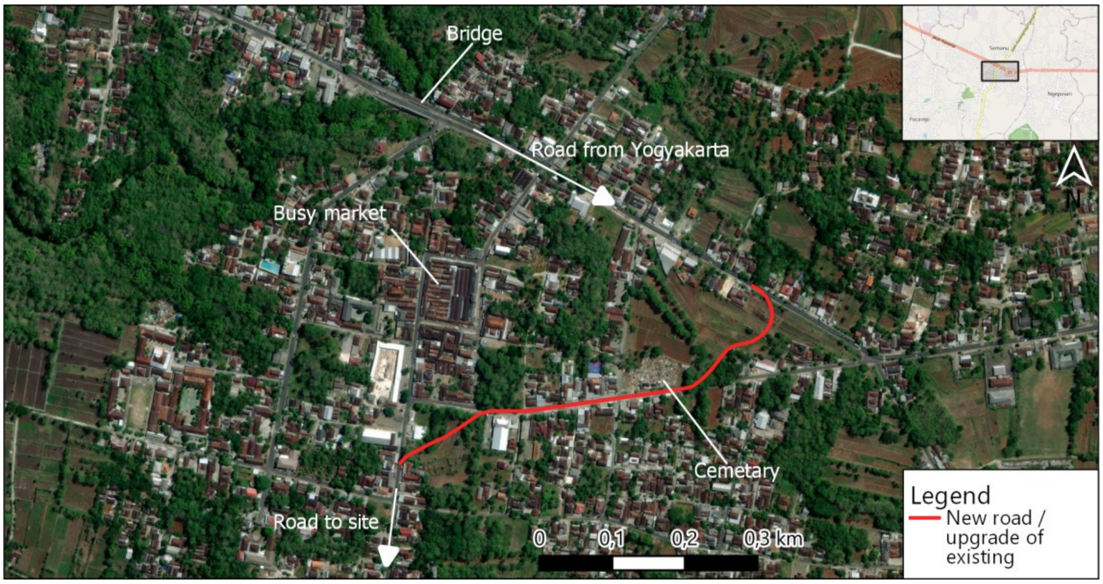

Figure 23. The red line is a possible new road to circumnavigate the center of Semanu, which has narrow roads and sharp turns.

As shown in Figure 24, an asphalted road connects Semanu to several villages within the site. The road from Semanu winds through the valleys, in the curves minor reconstruction (widening) might be necessary to accommodate transport of large turbine components.

Figure 24. The road connecting Semanu to the villages within the site. Roads will have to be cleared of overhanging trees/branches and in the curves some widening might be necessary. It is expected that after construction, the whole road needs asphalting due to the heavy transport.

2.4.3 Transport within the site

Within the site, new access roads will have to be constructed to the envisioned wind turbine sites. For the proposed road layout (see Figure 25), these access roads are connected to each other rather than using the narrow local roads as a backbone. Using these local roads is avoided as the existing roads are narrow and wind through villages with houses close to the road. When these existing roads are used, major reconstruction is necessary within the villages.

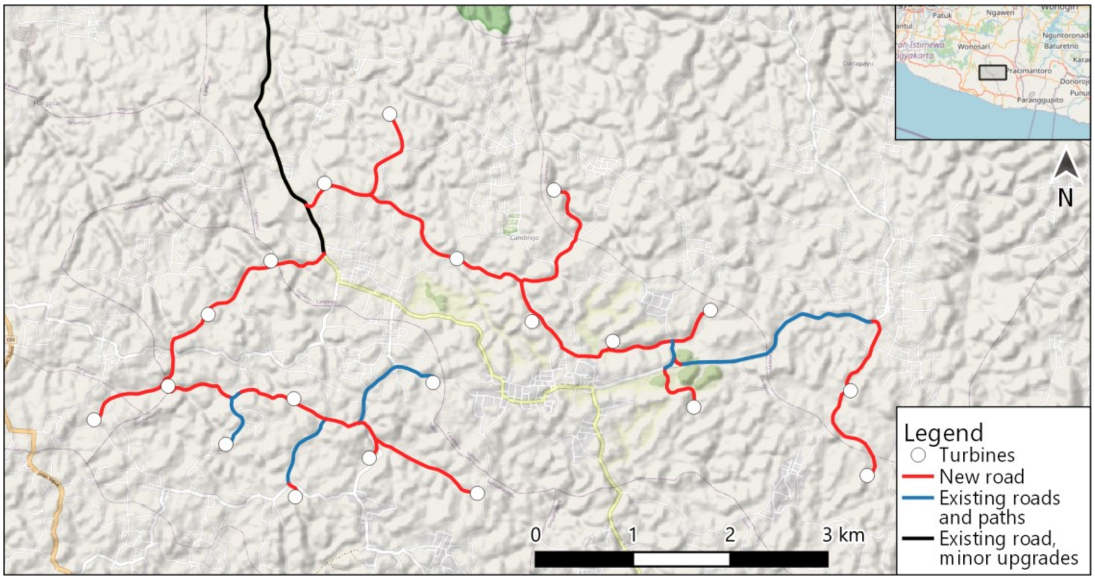

Figure 25. Road layout within site. This layout does not use the existing roads within the villages as major reconstruction is expected.

A total of 18.28 km new road and 5.20 km to-be-upgraded existing road is expected, not counting the more minor upgrades on the road to the site (shown as black lines in Figure 25). Figure 26 exemplifies the existing road that requires an upgrade. Additionally, Figure 27 presents the open fields in which new roads can be constructed.

Figure 26. Roads to be upgraded.

Figure 27. Fields in which new roads can be constructed.

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 possible road improvements between the toll road near Yogyakarta (near Prambanan) and Gunung Kidul. Online articles suggest that after the toll road is finished, road upgrades may happen to further improve connections to Gunung Kidul; and
- Check whether train powerline removal at the train track crossing is necessary.

2.5 Geology and seismicity conditions

The site is located in the 'Sewu Mountains,' a hilly/mountainous plateau stretching along the south coast in Gunung Kidul and Wonogiri Regency.

2.5.1 Geology

As shown in Figure 28, the rocks on the surface at the wind farm site are from the Wonosari Formation, consisting of crystalline limestone, reef limestone, carbonate sandstone, carbonate siltstone, clastic limestone, and lignite-infused siltstone. Limestone is composed of fossil fragments, shell fragments, and calcite (Kurniandi et al., 2017).

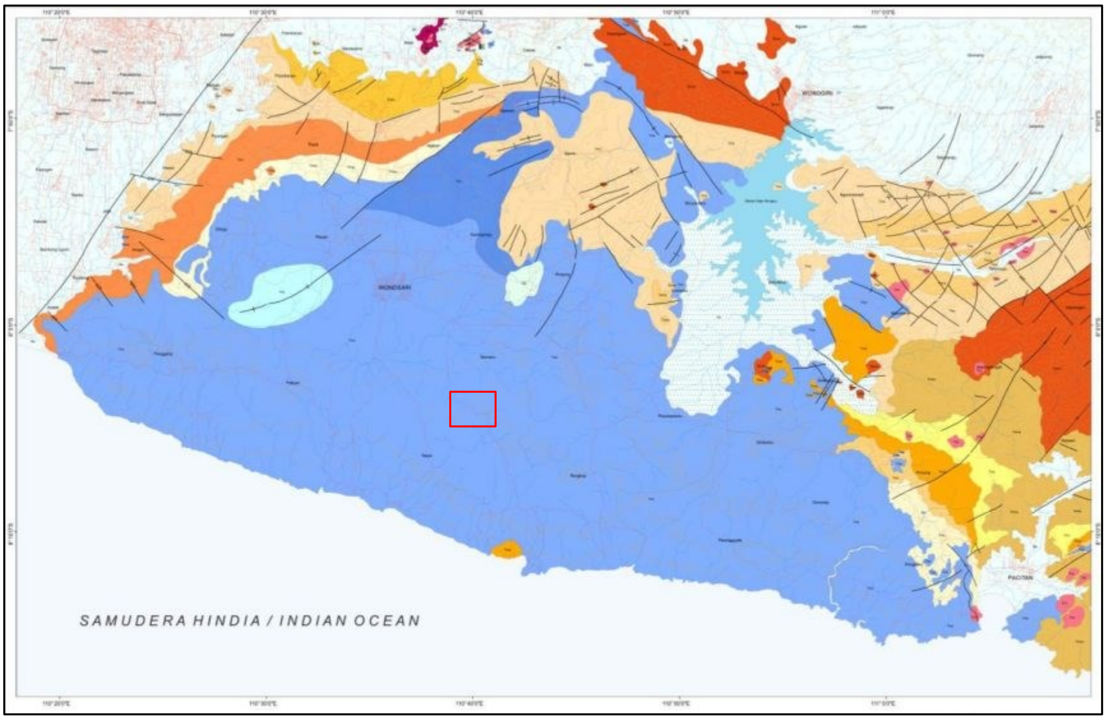

Figure 28. Geological map of the region. The colors indicate the geological formations at the surface. The largest blue formation is the Wonosari Formation, consisting of carbonates. Site location is shown within the red box.

Carbonate rocks lie at the surface and make up the 'Sewu Mountains,' which creates a karst landscape. This is the result of the (relatively easy) weathering of these rocks by dissolution of carbonate in water. In the area, some larger vertical and horizontal caves a known (i.e. Jomblang Cave, Setro Cave). It is likely that within the site, caves or smaller cavities are present below the surface. During the geotechnical assessment, special attention is required to the presence of these cavities directly below and around the envisioned wind turbines.

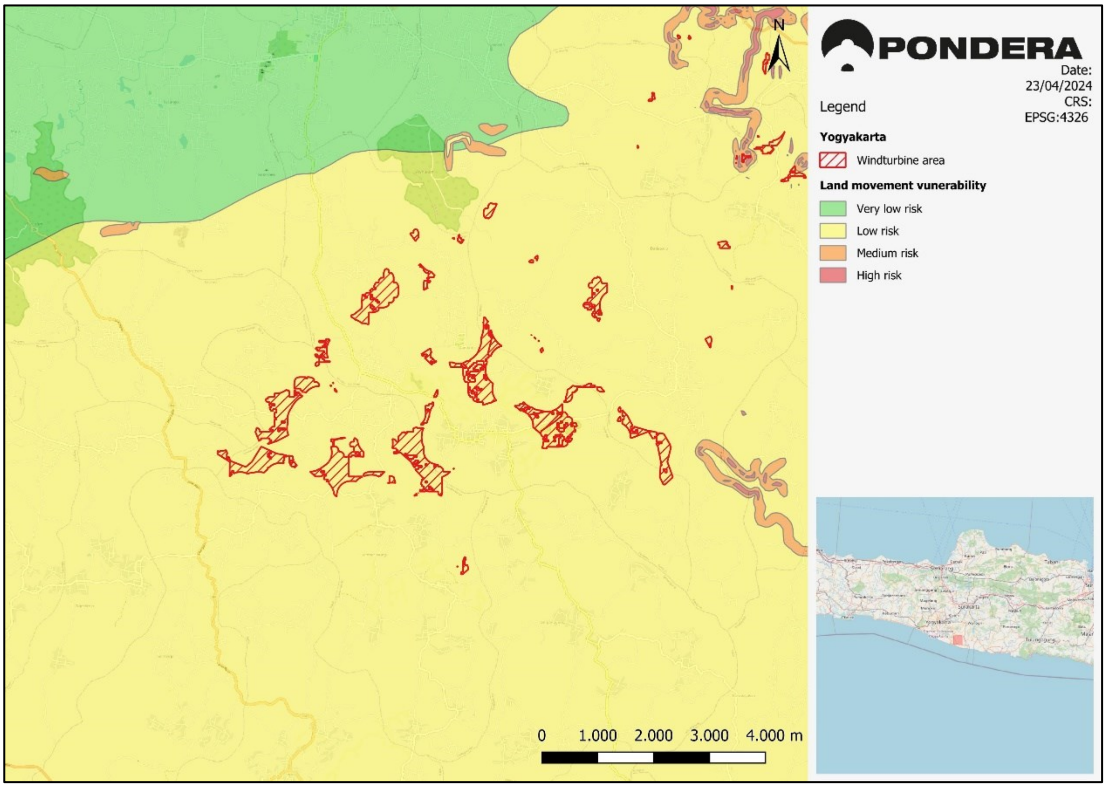

Figure 29. Land movement vulnerability index for Gunung Kidul.

Figure 29 visualizes land movement vulnerability index of the soil in and around the WTG-areas. According to the Land Movement Vulnerability Index, areas with steeper slopes are more vulnerable to land movement/landslides. Although the envisioned wind farm site is considered to have a low land movement vulnerability, further investigation is recommended. In the feasibility stage, the stability of the slope needs to be investigated further by a geotechnical soil investigation, which determines several soil characteristics (e.g. shear strength, density, permeability etc.), and a following soil stability analysis in combination with the LiDAR-study for a more precise mapping of the topography.

2.5.2 Seismicity

According to the geological map (see Figure 28), no faults are observed in the nearby area. The nearest faults are located near the edge of the plateau, in the southeast of Yogyakarta and between Yogyakarta and Wonogiri. 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 (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 30 provides a visual representation of the earthquake risk level in and around the WTG-area.

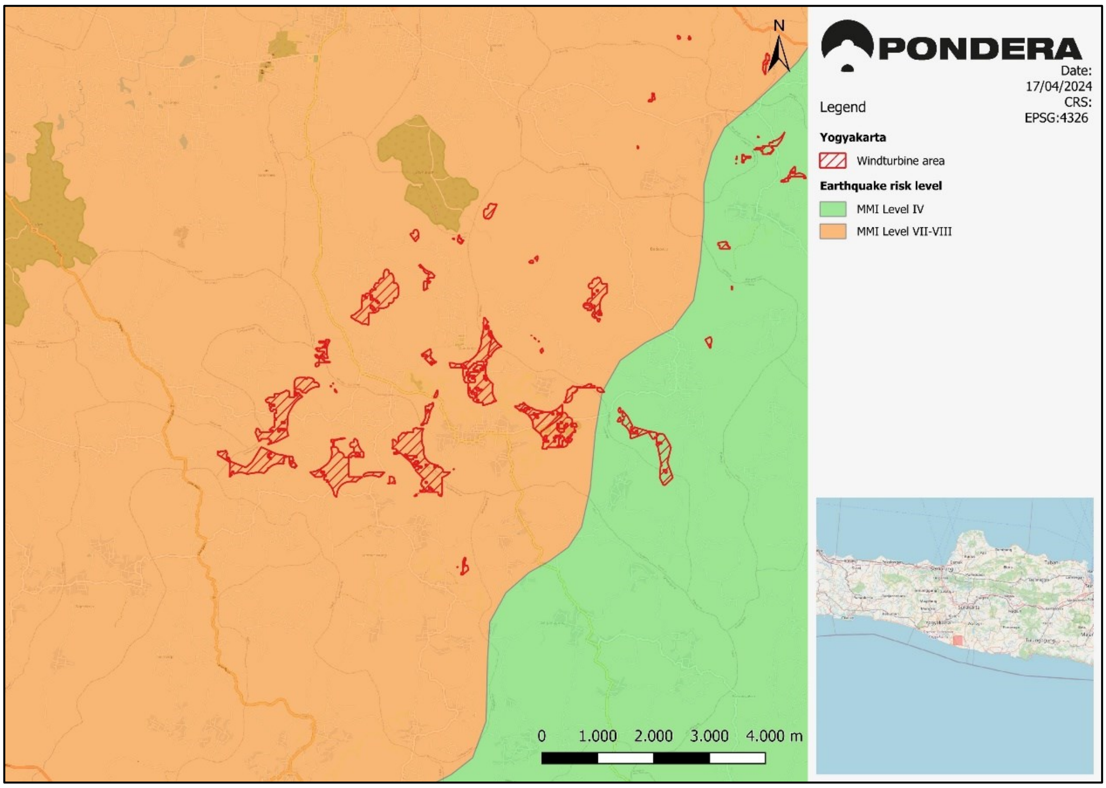

Figure 30. Earthquake hazard and risk level at Gunung Kidul.

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 is very homogeneous throughout the site. The terrain consists of small but steep hills (generally 150 x 300 x 30 to 40 m) which are used for agroforestry, and valleys in between which are in use by farmers. Corn is the primary crop that is grown. The general impression of the area is depicted in Figure 31, Figure 32, Figure 33, and Figure 34.

Figure 31. Impression of the area. Numerous small hills with valleys in between that are used by farmers and occupied by small villages.

Figure 32. Impression of the area. The slope of the hills can be very steep.


Figure 33. Impression of the area. In some areas, an existing road can be upgraded and used as an access road.


Figure 34. Impression of the area. Narrow road on the right, valley in center, and small but steep hill on the left.

2.6.2 Biodiversity and environmental impact

In the valleys, almost all areas are in agricultural use. The slope and top of the hills are used for agroforestry or forests. Primary forest does not occur within the site. On the hill slopes, some small scale open mines are or were active to excavate the carbonate rocks for cement. It is expected that these areas are not the highest ranking in terms of biodiversity. The forest (agroforest and 'unused' forest) is cut up by the agricultural fields in the valleys. This means that habitats of animals in the forests are already cut up into small sections. The main impacts are:

Biodiversity impact:

- Bird & bat strikes (turbines)
- Further habitat fragmentation (mainly 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 limited to bird & bat strikes and visual impacts.

Observed flora and fauna:

According to the online biodiversity database of Global Biodiversity Information Facility (GBIF), there is one recently observed animal species that are categorized in the IUCN global red list category (International Union for Conservation of Nature's Red List of Threatened Species) in the area (see Figure 35). 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[11]. 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
Acridotheres javanicus	Javan Myna	Vulnerable (VU)

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
-	-	-

Two bird species, namely *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.

Even with no endangered species, the development will still have an effect on biodiversity. Influence on the environment and biodiversity should be limited as much as possible.

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

Figure 35. 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 'least concern' or 'not evaluated.'

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 in 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 conducted during the feasibility phase.

2.6.3 Social impact

Settlements occur throughout the region. Small villages and isolated houses are situated in the valleys between the hills, but not all valleys are populated (see Figure 36). The potential turbines are placed at a distance of at least 300 meters from these dwellings.

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; and
- Increased mobility between certain areas when roads are improved.

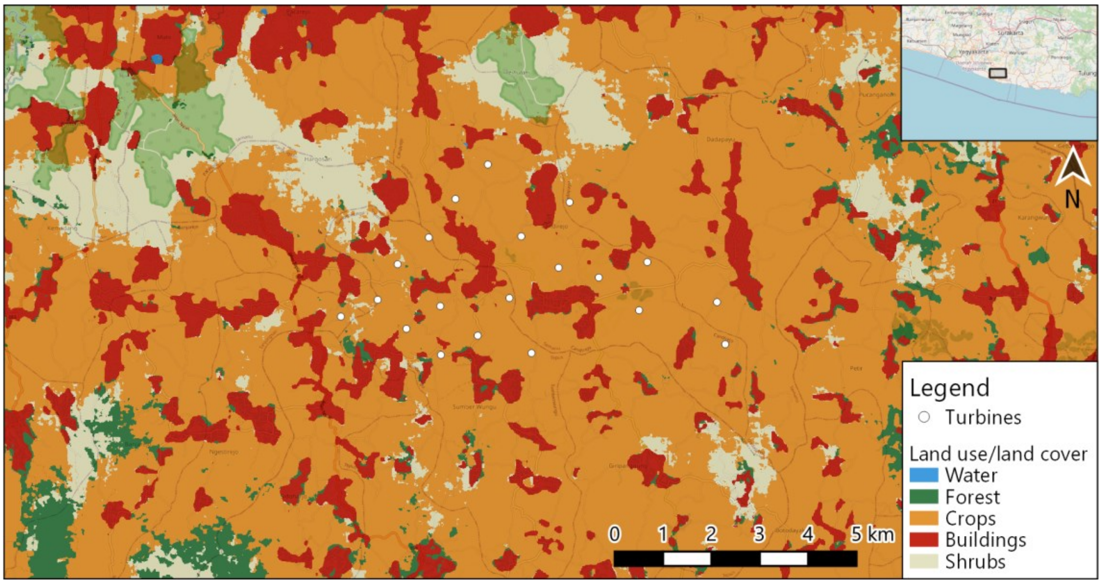

Figure 36. Land use map based on satellite imagery (ESRI/Sentinel 2, 2023). The area directly around the wind turbines is primarily covered by crops. The hilltops, which are mostly agroforests, are represented as crops in this dataset.

As the turbines are mostly built in unpopulated valleys and/or hills away from the villages, the social impact is mainly limited to the loss of agricultural land, reduced accessibility during road construction, and transport and visual impact.

The population of the villages within the wind farm area consists of a mix of farmers, small shops and restaurant (*warung*) owners. In the area, multiple small quarries (open pit) are active for the mining of limestone for cement production. The main commercial activity is concentrated in nearby towns of Semanu and Wonosari.

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 37. The annual population growth rate in Gunung Kidul declined from 1.97% in 2021 to 0.58% in 2023. Moreover, the population slightly increased in the period of 2019-2021.

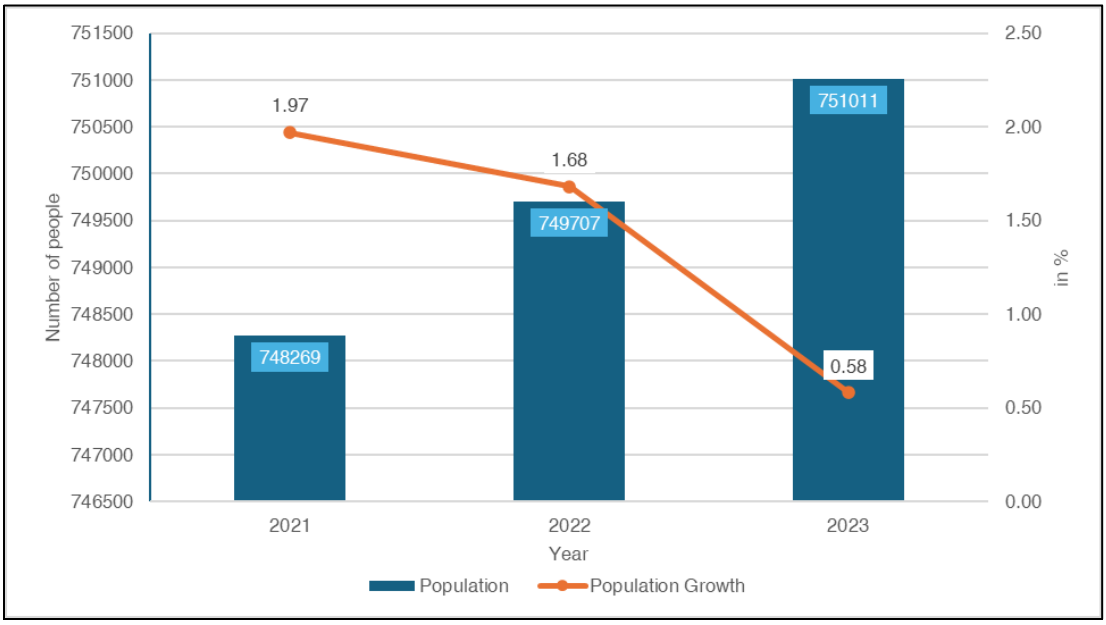

Figure 37. Population and annual population growth rate in Gunung Kidul in 2021-2023 (Source: [Statistics of Gunung Kidul Regency (bps.go.id)]).

The regency's population pyramid is shown in Figure 38. Moreover, the gender ratio in Gunung Kidul is 0.98 in 2023.

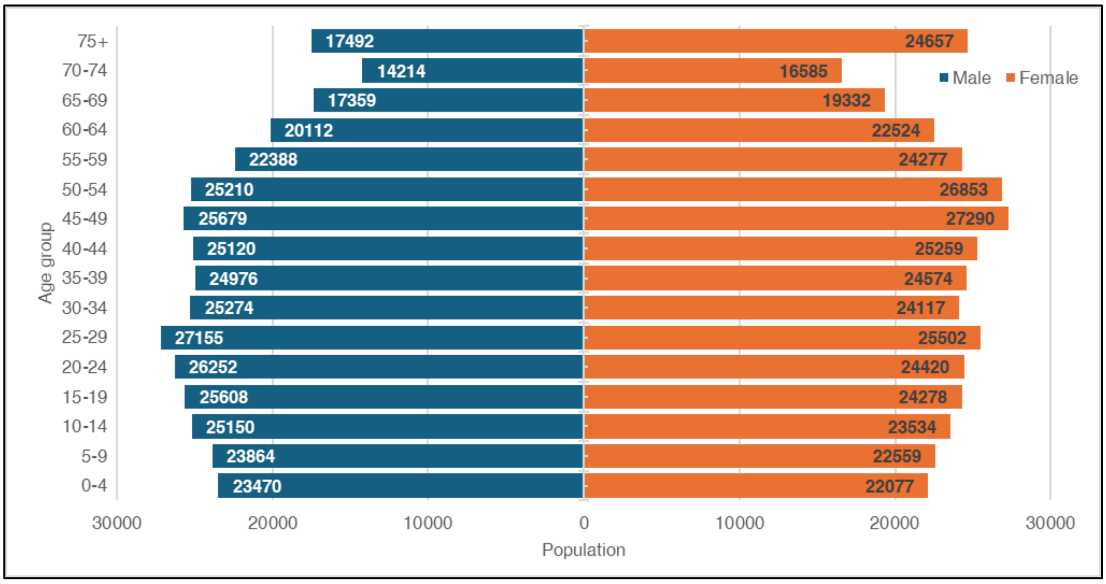

Figure 38. Population pyramid in Gunung Kidul Regency in 2020 (Source: [Statistics of Gunung Kidul Regency (bps.go.id)]).

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. These rates are displayed in Table 3. The labor force participation rate in Gunung Kidul in 2023 was 76.66%, increased from the two previous years. Meanwhile, there is a slight increase in the unemployment rate from 2022 to 2023.

Table 3. Labor force participation rate and unemployment rate in Gunung Kidul Regency in 2021-2023 (Source: Statistics of Gunung Kidul Regency (bps.go.id)).

Metric (in %)	Year		
	2021	2022	2023
Labor force participation rate	75.99	74.07	76.66
Unemployment rate	2.20	2.08	2.09

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

Table 4. Workers according to highest education (people) in Gunung Kidul Regency in 2023 (Source: Statistics of Gunung Kidul Regency (bps.go.id).

Educational attainment	Working	Unemployed	Total of Economically Active	Percentage of Working to Economically Active
Primary school (SD)	201,158	661	201,819	99.67
Middle school (SMP)	95,658	2,334	97,992	97.62
High school (SMA)	130,956	6,148	137,104	95.52
University	31,414	647	32,061	97.98
Total	**459,186**	**9,790**	**468,976**	**97.91**

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. The rates are shown in Table 5.

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

Pure participation rate	Year	
Educational level	**2022**	**2023**
Primary school	99.02	98.89
Middle school	90.93	83.03
High school	63.29	66.81

The number of educational facilities in Gunung Kidul Regency in 2022 is shown in Table 6. In total, there were 549 units of primary school and 43 units of middle school.

Table 6. Educational facilities in Gunung Kidul Regency in 2022 (Source: [Statistics of Gunung Kidul Regency (bps.go.id)]).

	Number of Primary School	Number of Islamic Primary School	Number of Middle School	Number of Islamic Middle School	Number of Kindergartens	Number of Islamic Kindergartens
School units	466	83	31	12	573	97

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 Gunung Kidul Regency from 2021 to 2023 shows a generally increasing trend, as shown in Table 7.

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

Metric	Year		
	2021	2022	2023
Human Development Index	70.37	71.18	71.46
Gender Empowerment Index	76.70	77.93	77.30
Gender Development Index	85.31	85.82	85.93

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 of Gunung Kidul Regency from 2021 to 2023 had a general increment, 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 Gunung Kidul regency from 2021 to 2023 had steady increment, 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 Semanu 150 kV PLN substation was selected for this, located in the east of the village of Wonosari. The aerial photo of this substation is included in Figure 39. 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 there 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 39. Location of the Semanu 150 kV PLN substation. Source: Google Maps.

2.7.2 Schematic design transmission and distribution network

In Figure 40, the schematic design of the transmission and distribution network is illustrated. The 20 wind turbines will each have a 20 kV output (via a 5 MVA transformer per wind turbine) which is distributed via distribution cables. Per string of maximum 10 wind turbines, the generated electricity is distributed to one of the two 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 Semanu substation.

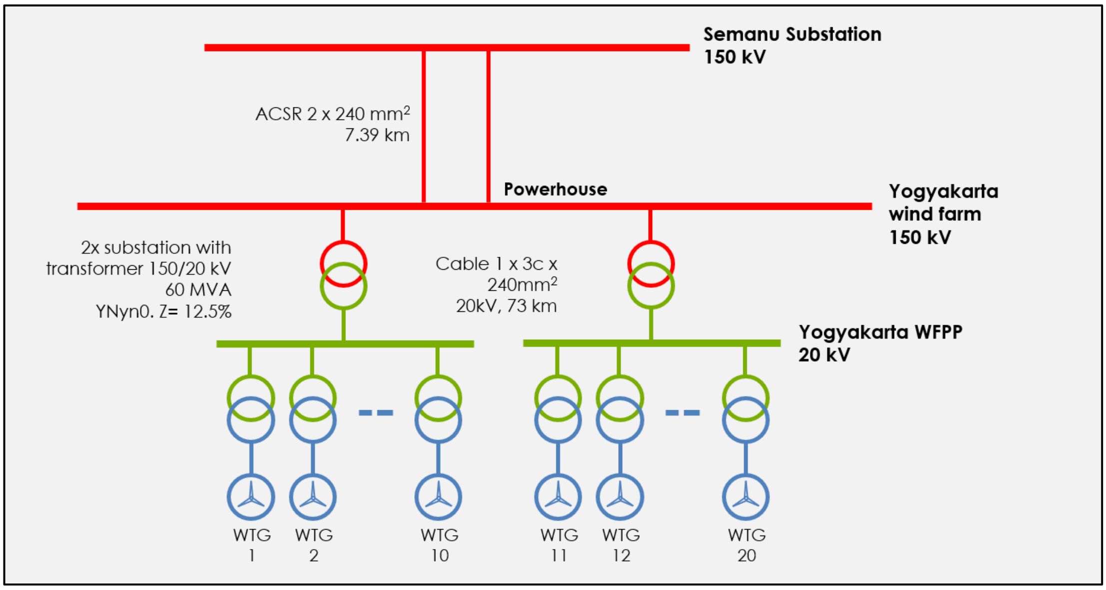

Figure 40. A schematic design of the transmission and distribution network at the envisioned Gunung Kidul wind farm

The overhead transmission line between the powerhouse and the PLN substation is assumed to be a straight line between both locations, covering 7 km as visualized in Figure 41. A total of 21 towers are planned with an intermediating distance between the towers of 340-450 m.

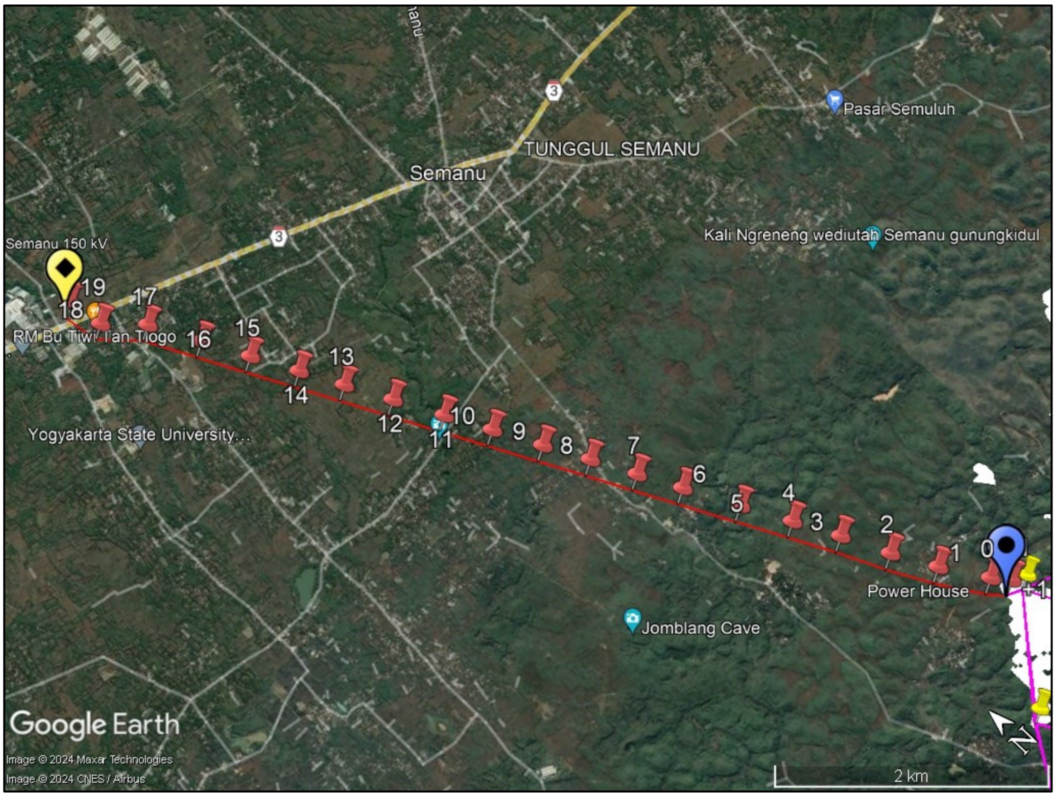

Figure 41. A schematic representation of the position of overhead transmission line between the powerhouse and the Semanu substation

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 Gunung Kidul site, the long-term wind speeds are determined based on the Global Wind Atlas (GWA) generalized wind climate and windPRO modelling. The mesoscale grid points from the GWA provide a first global look into the flow patterns and wind speeds in the region.

Figure 42 shows the resulting climatology at the locations of the WTGs. The modeled long-term wind speed, which is averaged over all 20 WTGs at the planned hub height of 140 m, is 6.0 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.

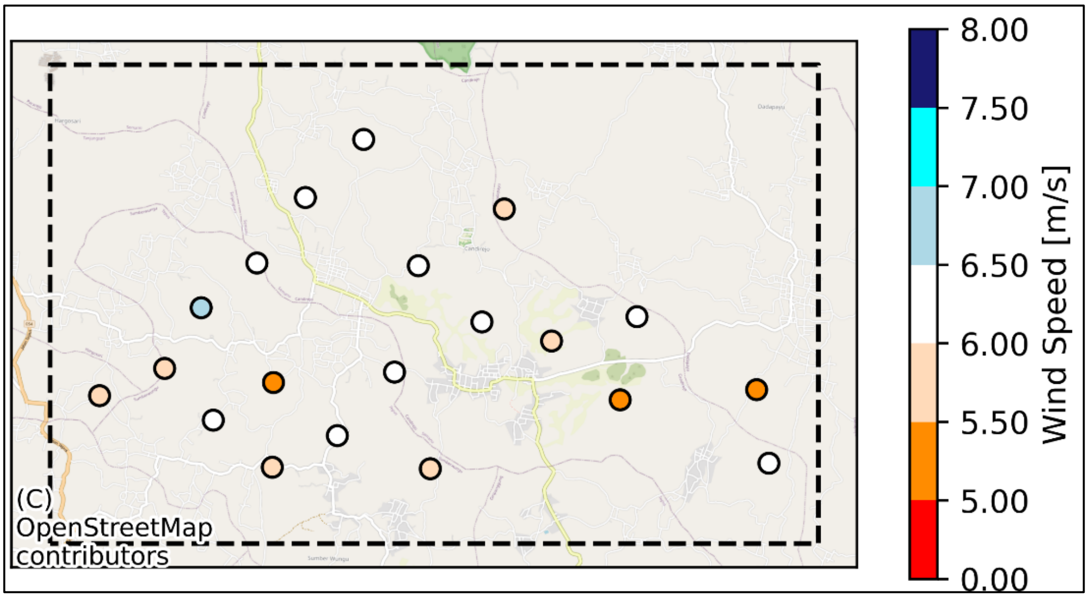

Figure 42. Long-term average wind speed results with the windPRO model at a height of 140 m at the turbine locations. The black-bordered circles represent the wind turbines, whereas the colors within the circle indicate the respective long-term average wind speed.

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 [%]	4.8%	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 4.8%.
	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)[12] 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.

[12] 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 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 [%]		**17.2%**	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 20 WTGs at the Gunung Kidul wind farm.

Parameter [Unit]	Amount
Number of new WTGs	20
Rated Power per WTG [MW]	4.0
Total rated Power [MW]	80.0
Rotor diameter [m]	~170
Hub height [m]	140
Air density [kg/m3]	1.129
Wind speed [m/s]	6.0
Gross result [MWh/yr]	263,586
Gross results including wake effects [MWh/yr]	251,048
P50 [MWh/yr]	**218,339**
P90 (25 yr) [MWh/yr]	**188,885**
P50 [hrs/yr]	2,729
P90 (25 yr) [hrs/yr]	2,361

2.8.3 Power output variation

In Subsection 2.8.2, we have provided an estimate of the P50 annual production, equal to 218,339 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 39 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 windPRO results 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.

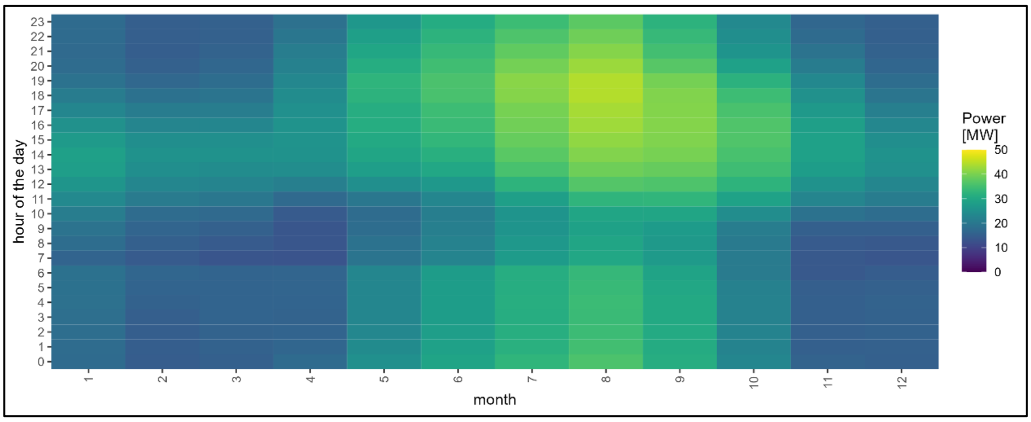

Figure 39: Overview of the monthly variation of wind farm average power output per hour of the day based on the P50 values from Subsection 2.8.2 in combination with the monthly and hourly variation in wind speed from EMD-WRF.

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 (3 met mast, each one year measurements)
- 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 20 wind turbines at the wind farm are shown in Table 10.

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

Main component	Quantity
Nacelle incl. generator (4 MW)	20 pcs
Blade (85 m)	60 pcs
Tower segments (total 140 m height)	120 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 Semarang 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.

Civil works

The quantities which are relevant for the civil works necessary for the installation of 20 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	18 km
	Upgrading existing road	12 km
Strengthening bridges (incl. design, materials, transport, labor)	Concrete bridge strengthening	23 bridges
Foundations (incl. design, materials, transport, labor)	Anchors (72 per foundation)	1,440 pcs
	Anchor cages	20 pcs
	Concrete (230m3 per foundation)	4,600 m^3
	Steel (35 tons per foundation)	700 tons
Crane hardstands (incl. design, materials, transport, labor)	Crane hardstands (50 x 100 m) using gravel	20 hardstands

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

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

- Civil works are including design, materials, transport, and labor;
- Large parts of the road to the site are in good condition and are in daily use by heavy traffic. From the ports of Semarang and Surabaya a highway is finished or under construction until Yogyakarta. Until the site, no major redesign is expected, except for bridge strengthening and a small redesign of a road in Semanu;
- Within the site, mostly new roads are planned as the existing (asphalted) roads are narrow and lead through small villages leaving very little space;
- 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 (6 km, 48 towers)	Transmission towers	21 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	20 pcs
	LV switchgear	1 pc
	DC Supplies	1 pc
	Lightning protection	1 pc
	2x3C 300 mm cable	567 m
Wind farm electrical works (between the powerhouse, substations, and wind turbines)	Transformers 20 kV (5 MVA)	20 pcs
	Switchgear	20 pcs
	MVAC Cable (1 x 3c x 240) 50 and 300 meters	73 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

Main component	Sub-component	Quantity
Substations (two for the entire wind farm)	Transformer 150/20 kV 30 MVA	2 pcs
	Neutral Grounding Resistor	2 pcs
	Switchyard	1 pc
	In/outgoing bays, coupler, busbars, Panel RCP	2 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[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 2,765,000	DEVEX: Prior to Financial Close	90% - baseline -120%
Project management	USD 6,164,000	DEVEX: Until CoD	Baseline
Wind turbines	USD 55,746,000	CAPEX: Including transport and installation	90% - baseline -120%
Civil works: foundations	USD 8,014,000	CAPEX	80% - baseline -150%
Civil works: roads	USD 15,503,000	CAPEX	80% - baseline -150%
Civil works: crane hardstands	USD 2,450,000	CAPEX	80% - baseline -150%
Electrical works	USD 19,378,000	CAPEX	90% - baseline -120%
Land acquisition	USD 21,434,000	CAPEX	90% - baseline -150%
Risk contingencies	USD 9,863,000	DEVEX + CAPEX	Baseline
Lower bound total investment cost (DEVEX + CAPEX)	**USD 126,452,000**	**Investment cost per MW: USD 1,581,000**	
Baseline total investment cost (DEVEX + CAPEX)	**USD 141,578,000**	**Investment cost per MW: USD 1,770,000**	
Upper bound total investment cost (DEVEX + CAPEX)	**USD 180,857,000**	**Investment cost per MW: USD 2,261,000**	
Baseline operational expenditure (OPEX)	**USD 2,404,000 / 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 1.0 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	8.40%	6.61%	3.20%
Average Debt Service Coverage Ratio (DSCR) at P90	0.90	0.82	0.66
Net profit at P50 over 25 years	USD 58,488,000	USD 43,708,000	USD 4,547,000

3 Conclusion and Recommendations

Based on the conducted analysis, it is concluded that the overall techno-economic viability of a wind farm in the Gunung Kidul region requires improvement. The main cause for this is the lower wind speeds occurring in the region. Based on the initial wind resource assessment derived from the Global Wind Atlas, wind speeds much higher than 6 m/s were not expected. Moreover, during the wind modelling stage, the long-term average wind speed at some wind turbine locations turned out to be even below this number (see Figure 42). This is caused by the effect of the topography on the wind characteristics, which is to a lesser extent notable when creating a wind speed map based on Global Wind Atlas.

This does not mean that the possibility of a wind farm in Gunung Kidul should be completely written off. We recommend reconsidering the site's layout during a follow up study, in which the focus is on the wind turbine location where the long-term average wind speed exceeds 6 m/s. This could lead to a wind farm size of approximately 30-40 MW, with potentially a higher average energy yield per wind turbine. Furthermore, specific components drive up the investment cost significantly. The strengthening of 23 bridges is a major cost factor (+/- 7% of the investment cost) for this wind farm. In a follow up study, the aim should be to find cost savings for this cost (see specific recommendations under *Transport*). Lastly, the land acquisition costs for this project are significant (+/- 15% of the investment cost). This is caused by the plan to build the wind farm on moderate fertile areas, which have a higher acquisition cost than low quality soils at remote areas. Aside from trying to negotiate for a lower land acquisition price, less wind turbines and less infrastructure will require less land acquisition. Optimizations can be sought to lower this cost.

Aside from the lack of wind resources at several wind turbine locations and some high cost factors, 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. We recommend placing at least three met masts for data gathering for at least one year (see Figure 43). 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.

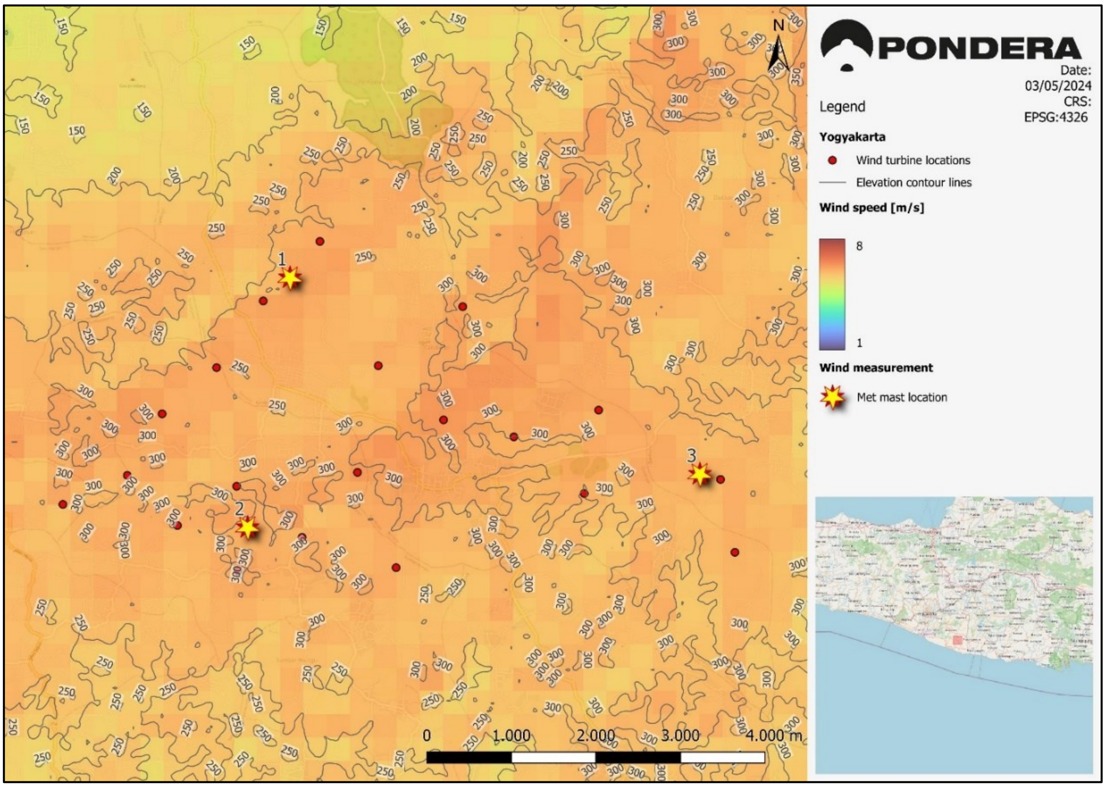

Figure 43. Recommended met mast locations.

- **Land use and permitting:** As can be derived from Figure 36 and Subsection 2.2.5, the wind farm is planned in Dryland Farming/Agricultural Area. For that reason, it will be necessary to get to an agreement with the landowners 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 firstly 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. To ensure that the port in Semarang or 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. Large parts of the road to the site are in good condition and are in daily use by heavy traffic. However, within the site, mostly new roads are planned whereas the existing (asphalted) roads are narrow and lead through small villages leaving very little space. Optimization should be sought to lower the cost for new roads. The same goes for the strengthening of the 23 bridges. Further analysis is required to determine the current strength of these bridges and the necessity to strengthen them. In case strengthening of bridges is required, it is worth investigating if Government infrastructure funds are available to cover a part of the strengthening cost. In general, a more extensive logistical survey is recommended to be conducted as part of the future feasibility study to obtain more details of the required infrastructure (adjustments).

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

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

- **Environment:** Although the wind farm location is not a densely populated area, there will be visual impact on the area because of the use of wind turbines with a tip height of more than 200 m. The presence of this wind farm could cause opposition from local stakeholders and environmental groups on 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 a vulnerable fauna species is present in the envisioned wind farm area. Hence, it is likely that the wind farm development will have an effect on biodiversity. It is also 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 80 MW of wind energy (with variable output), and that the substation in Semanu 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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