iFOREST | INTERNATIONAL FORUM FOR ENVIRONMENT, SUSTAINABILITY & TECHNOLOGY

WEST BENGAL RENEWABLE ENERGY POTENTIAL RE-ASSESSMENT

Focus on Solar, Wind and Biomass

September 2024

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List of Abbreviations

AGL	Above Ground Level
CUF	Capacity Utilization Factor
CWC	Central Water Commission
GPP	Gross Primary Production
GRID	Global Resource Information Database
GW	Giga Watt
GWA	Global Wind Atlas
GWh	Giga Watt hour
ISRO	Indian Space Research Organisation
KT	kilo Tonne
kV	kilo Volt
kW	kilo Watt
kWh	kilo Watt hour
kWp	kilo Watt peak
LULC	Land Use and Land Cover
MJ	Mega Joule
ML	Machine Learning
MNRE	Ministry of New and Renewable Energy
MODIS	Moderate Resolution Imaging Spectroradiometer
MT	Metric Tonne
MW	Mega Watt
MWp	Mega Watt peak
NISE	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NRLD	National Register for Large Dams
NRSC	National Remote Sensing Centre
PV	Photo Voltaic
RE	Renewable Energy
RPO	Renewable Purchase Obligation
sq. km	Square kilometer
sq. m	Square meter
SRTM	Shuttle Radar Topography Mission
TIFAC	Technology Information Forecasting and Assessment Council
UNEP	United Nations Environment Programme
WBIS	Water Bodies Information System

Summary

West Bengal is assessed to have a limited renewable energy (RE) generation potential of 10,484 MW (including large hydro), accounting for about 0.5% of the nation's total. This perceived lack of potential has been a fundamental reason for the lack of investment momentum in the state's RE sector. At present, the RE potential assessment for most technologies has been undertaken over a decade ago and is largely based on generic thumb rules. There is a need to update these numbers to reflect new datasets and granular methodologies, to guide policymakers, implementing agencies, and investors in developing a strategic and ambitious RE capacity plan for the state. In this context, iFOREST has conducted a comprehensive re-assessment of the RE potential for West Bengal, covering ground-mounted solar, floating solar, wind energy and biomass:

Ground-mounted solar

- West Bengal enjoys more than 300 days of uninterrupted sunshine annually, amounting to approximately 2,280 sunny hours per year. The state receives an average solar radiation of 4.60 kWh per square meter and an average insolation of around 355 W per square meter. While the average insolation is low, the peak insolation is about 972 W per square meter, comparable to India's leading RE states.
- In contrast to the MNRE's conservative assumption of utilizing 3% of wasteland for solar PV installations, a detailed assessment of the availability of suitable wasteland types suggests a higher utilization of 9% (after applying various climate and ecological filters). This amounts to a solar ground-mounted potential of 19,041 MW, spread across 385 sq. km of area, which is more than three times the MNRE estimated potential of 6,260 MW. District-wise, 56% of the assessed potential is concentrated in Puruliya due to the high availability of open scrubland. This is followed by Bankura and Paschim Bardhaman districts which account for 13% and 7% of the assessed potential respectively.
- 12 small to large clusters of wasteland parcels are identified across seven districts of Puruliya, Birbhum, Paschim Bardhaman, Jhargram, and Paschim Medinipur. These clusters aggregate to an area of 215.34 sq. km and are capable of supporting a total solar capacity of 1,054 MW (at the assumed level of land utilization).
- Further, a wasteland area of 121.98 sq. km is identified to be available near existing transmission substations, which can be prioritized for development. This land area can support nearly 2,280 MW of solar capacity (assuming 100% land utilization).

Floating solar

- Across the 30 dams existing in West Bengal, the floating solar PV potential is estimated to be 715 MW in the low utilization scenario, 1,784 MW in the medium utilization scenario and 3,567 MW in the high utilization scenario.
- The assessed potential is concentrated in the Bankura district (with a 1,986 MW potential across three reservoirs) and the Puruliya district (with 1,225 MW potential across 21 reservoirs). Kangsabati Dam provides the largest individual potential of a 1,790 MW floating solar plant.

Wind

- Mapping of high wind speed locations and filtering for climate risks and high slopes, a theoretical potential of 19.69 GW is identified at a hub height of 100 m above ground level (AGL) and of 22.79 GW at 150 m AGL hub height. About 6 GW of the potential at 150 m hub height is identified at high wind speeds of 6 to 7 m/s.

- Focusing specifically on wastelands, based on a similar methodology, a wind energy potential of 115 MW and 1,677 MW is identified at 100 m and 150 m AGL, respectively. Uttar Dinajpur accounts for the highest potential with a share of 20%, followed by Maldah with a 15% share, Paschim Medinipur and Murshidabad with a 12% share each, and Jhargram and South Twenty-Four Parganas with 10% share each.

Biomass

- Based on the district-wise crop residue data from 'ISRO JAIVOORJA' portal, the cumulative biomass potential of West Bengal is estimated to be 2,864 MW, which is nearly double the MNRE assessment. Three districts of Paschim Medinipur, South 24 Parganas and Purba Bardhhaman account for nearly half of the assessed potential, with 18%, 17% and 13% share respectively.

Overall, the reassessment of West Bengal's RE potential indicates that the state possesses significantly higher RE capacity than previously estimated by the MNRE. This enhanced potential is sufficient to support the addition of substantial RE capacity in the state, facilitating a long-term transition to green energy at both utility and captive/industrial scales.

1. Introduction

Historically, West Bengal has been at the forefront of renewable energy (RE) development. India's first grid-connected solar plant of 2 MW capacity was commissioned in the state in 2009 at Jamuria, Paschim Bardhaman. One of India's first pumped storage hydro project was also set up in the state in 2007 at Purulia. India's first biomass gasifier-based power plant (of 500 kWp), the first small hydro plant (of 10 kW), and the first rooftop grid-connected solar power plant (25 kWp) were all installed in the state in 1996.

However, in recent years, West Bengal has fallen behind other states in renewable energy development. At present, 640 MW of RE capacity is installed in West Bengal, which is less than 1% of India's total which stands at 144,751 MW (as of April 2024). Source-wise, the RE capacity consists of 54 per cent biopower, 18 per cent ground-mounted solar, 15 per cent small hydro, 11 per cent solar rooftop, and 2 per cent off-grid solar. The biopower capacity of 348.3 MW, consists largely of biomass/bagasse cogeneration (300 MW).

A fundamental reason for the lack of investment momentum in the state's RE sector is the perceived lack of potential. According to assessments by the Ministry of New and Renewable Energy, the state has an estimated RE potential of 10,484 MW, about 0.5 per cent of the nation's total. Most of this potential accrues to solar energy (6,260 MW), followed by biomass (1,742 MW) and wind (1,281 MW)[1].

Table 1.1: Source-wise potential of RE capacity in West Bengal

RE source	Estimated potential (MW)
Wind (at 150m agl)	1,281
Small hydro	392
Biomass	1,742
Cogeneration-bagasse	-
Solar	6,260
Large hydro	809
Total	10,484

Source: MNRE

Aside from the potential of wind power, the potential across other technologies has been estimated over a decade ago and are largely based on generic thumb rules. It is thus significantly underestimating the actual potential and is in effect failing to inspire the necessary policy action and investment from state decision-makers and RE investors.

To address this, a more detailed and granular assessment of RE potential is required for each RE technology. This should include an evaluation of potential sites and clusters, employing more accurate methodologies and updated datasets. Such an assessment is essential to guide policymakers, implementing agencies, and investors in developing a strategic and ambitious RE capacity plan for the state in the short to medium term. This strategy will be crucial for West Bengal to meet its RPO targets and achieve sustainable green energy growth. In this context, iFOREST has conducted a comprehensive assessment of the RE potential for West Bengal, covering ground-mounted solar, floating solar, wind energy and biomass. The subsequent chapters of this report present the reassessment.

2. Solar

The solar power generation potential of a given region is primarily determined by two critical factors: the quality of insolation and the availability of land for solar plant installations. West Bengal has traditionally been considered less favourable for utility-scale solar energy generation due to its relatively lower insolation intensity and limited availability of wasteland.

Despite the perceived disadvantages, West Bengal receives over 300 days of uninterrupted sunshine annually, amounting to approximately 2,280 hours of sunlight each year. The state experiences an average solar radiation of 4.60 kWh per square meter.[2]

Despite being on the same latitude as the eastern states, the average radiation in West Bengal is comparatively lower than its counterparts like Odisha, Jharkhand, Bihar etc. due to the prolonged monsoon season (typically from June to September). Heavy rainfall above 250 cm is observed in the Darjeeling, Jalpaiguri, Alipurduar and Cooch Behar districts. Overall, while the peak insolation of 972 W per sq. m is comparable to 'renewable energy (RE)-rich' states like Gujarat and Madhya Pradesh, the average insolation of 355 W per sq. m is lower than other 'low-RE' states like Odisha and Uttar Pradesh.[3]

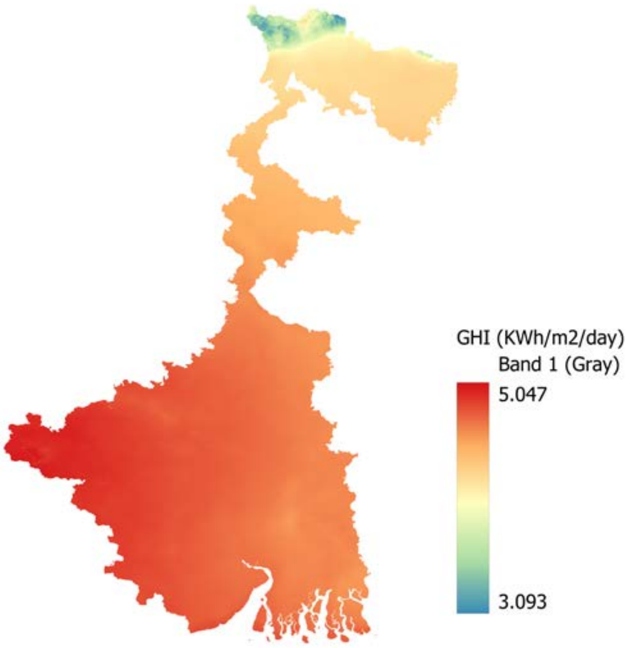
Further, there are wide variations in the solar resource at the district level. The average daily solar insolation follows a gradient from high in the western/southern region to low in the northern/eastern region of West Bengal.

Table 2.1: Average and peak insolation levels for key states

State	Average (W per sq. m)	Peak (W per sq. m)
West Bengal	355	972
Uttar Pradesh	465	889
Odisha	389	913
Madhya Pradesh	514	989
Gujarat	590	825
Germany	229	892

Source: NASA LaRC

Map 2.1: Solar insolation map of West Bengal



Source: Global Solar Atlas

The National Institute of Solar Energy (NISE), the Ministry of New and Renewable Energy`s (MNRE) apex institute for research and development in the solar power sector has estimated that West Bengal has a solar power generation potential of about 6.26 GW.[4] This assessment is based on a generic methodology that assumes that 3% of the available wasteland is utilized for solar PV installations. However, this approach may overlook the potential for greater land utilization in specific wasteland categories that can accommodate significantly higher than 3% solar panel coverage without causing significant ecological harm. For instance, industrial and mining wastelands can be repurposed extensively for solar installations within the state.

Additionally, it is essential to consider land-neutral solar technologies, such as floating and rooftop solar, which can be assessed more closely to minimize ecological impacts and explore alternatives beyond traditional ground-mounted installations. These technologies offer the potential to expand solar capacity without further straining land resources, thereby supporting sustainable energy development in the state.

2.1 Ground-mounted solar

Along with sufficient solar insolation, land availability is a major parameter defining the potential and feasibility of the installation of ground-mounted solar PV projects. Typically, installing 1 MW of solar capacity requires five acres of land[5]. Given the land requirement intensity for ground-mounted solar projects, wastelands are considered most suitable for utility-scale ground-mounted solar projects.

The existing potential assessment methodology utilized by NISE is overly simplistic, as it uniformly applies a 3% utilisation rate across all states without considering the unique characteristics of each region. However, certain categories of wasteland can support a higher proportion of land diversion for solar power generation without causing significant ecological damage. For a more accurate assessment of West Bengal's ground-mounted solar potential, it is essential to analyse the state's specific land use patterns and wasteland categorization. By doing so, a more nuanced and realistic estimate of the state's solar generation capacity can be developed, considering the potential for higher land utilization in certain wasteland types.

Re-assessment methodology

To reassess the ground-mounted solar potential of West Bengal, recent district-wise wasteland data is categorised for various wasteland categories which were filtered for non-desired features such as high propensity to floods, high elevation, fire density, cyclones etc.

To accurately identify wasteland distribution, a pixel-based classification machine learning (ML) model applied to multispectral imageries from Sentinel-2 was designed[6]. The 2015-16 wasteland feature classes serve as a reference for understanding and selecting training samples, which form the foundational data for model training. This training process is further supplemented by manual verification. Additionally, closely identified manual training samples, derived from year-wise and seasonally varied Sentinel-2 imagery, are incorporated to enhance the model's accuracy and robustness. *(Refer to Box 2.1 for the step-by-step methodology of wasteland mapping)*

The mapped wasteland was further analysed to identify regions with high susceptibility to natural hazards such as floods, landslides and cyclones. The flood, cyclone and landslide-prone areas were determined using a database from the Global Resource Information Database (GRID) of the United Nations Environment Programme (UNEP)[7]. Additionally, regions of high elevation, which are more prone to landslides, were clipped from the wasteland dataset based on topographical data provided by the University of California, San Diego's Topography platform.[8] The process of identification and filtering of pixels with slopes higher than 8 degrees was executed using R software (R studio).

- Fire-prone areas were identified as active fire density areas for the period January 2022 to December 2022 wherein the density of fires is reported as the count of fire per sq. km filtered for fire density greater than 0.1.
- Flood-prone regions represent 25 years of modelled data for floods with water levels greater than 180 cm.

- Landslide-prone areas reflect the annual frequency of landslides triggered by precipitation. This was filtered for medium and high frequencies.
- The cyclone dataset includes an estimation of the frequency of Saffir-Simpson category 5.
- A slope of 8 degrees or above is considered undesirable for solar projects.

For the reassessment of solar energy potential on the clipped wasteland areas, new utilization factors were applied to different types of land depending on ecological sensitivity. For the present assessment, 60% of the mining wasteland was assumed to be utilized for solar panel installation; 50% of industrial and baren-rocky & stone wastelands; 35% of open scrubland; and 25% of sand riverine & dense scrubland. These factors were employed to estimate the feasible land area available for solar energy projects, considering the varying degrees of land usability.

For the identified wasteland areas, based on the higher utilization assumptions, the solar energy potential was calculated. The calculation assumed that 1 MW of solar power generation would require five acres of land, as per the current industry standard. This approach provided a quantitative estimate of the solar potential that could be harnessed from the available wasteland, facilitating strategic planning for solar deployment.

BOX 2.1: METHODOLOGY FOR WASTELAND MAPPING

Step 1 - Imagery Review: Sentinel-2 imageries at a 10-meter resolution have been reviewed across different seasons—Rabi, Kharif, and Zaid—to capture and analyse seasonal variations.

Step 2 - Mosaic Generation: A mosaic layer has been generated using the Sentinel-2 L1C dataset, which consists of 13-band imagery. This imagery has been downloaded from the Copernicus Data Space platform. An empty raster dataset has been created using the 'Create Raster Dataset' tool, configured according to the Sentinel-2 MSI specifications, including 13 bands with a 10-meter resolution. The mosaic has been generated using ArcGIS Enterprise Tooling, particularly ArcPro and the Deep Learning Toolkit. This process integrates the downloaded images into a single, comprehensive mosaic, facilitating detailed analysis and visualization.

Step 3 - Training Dataset: A training dataset was created by clipping 4 to 6 test regions from the mosaic layer. Supervised classification was then performed on these clipped regions to identify the desired wasteland classes using the image classification tool. The training set was developed with reference to the National Remote Sensing Centre (NRSC) Wasteland Dataset of 2019 and was adjusted based on our understanding of both the latest and previous imagery. The initial output was in raster format, which was then converted to vector format. Following this conversion, the vector shapefile has been edited to further refine the output, enhancing the data's accuracy and usability for subsequent analyses.

Step 4 - Seasonal Model Development: Distinct models have been developed for each agricultural season—Rabi, Kharif, and Zaid. Training samples specific to each season have been collected and used to train these models, using Sentinel-2 imagery paired with corresponding ground truth data. Each seasonal model has been optimized to perform effectively during its respective season, capturing the unique characteristics and patterns relevant to that period.

Step 5 - Combined Model Integration: Once the seasonal models are trained and validated, they have been integrated into a single, unified model. During the inference phase, input imagery has been processed through all three seasonal models. The output probabilities or predictions from each model have then been aggregated using ensemble methods such as averaging, weighted averaging, or stacking. This approach allows the combined model to deliver a comprehensive output that reflects an understanding of land types across all seasons, effectively leveraging the strengths of each individual seasonal model.

Step 6 - Training Chip Set Generation: A training chip set has been generated using ArcGIS Enterprise Tooling, specifically ArcPro and the Deep Learning Toolkit. The input for this process

Box 2.1 continued

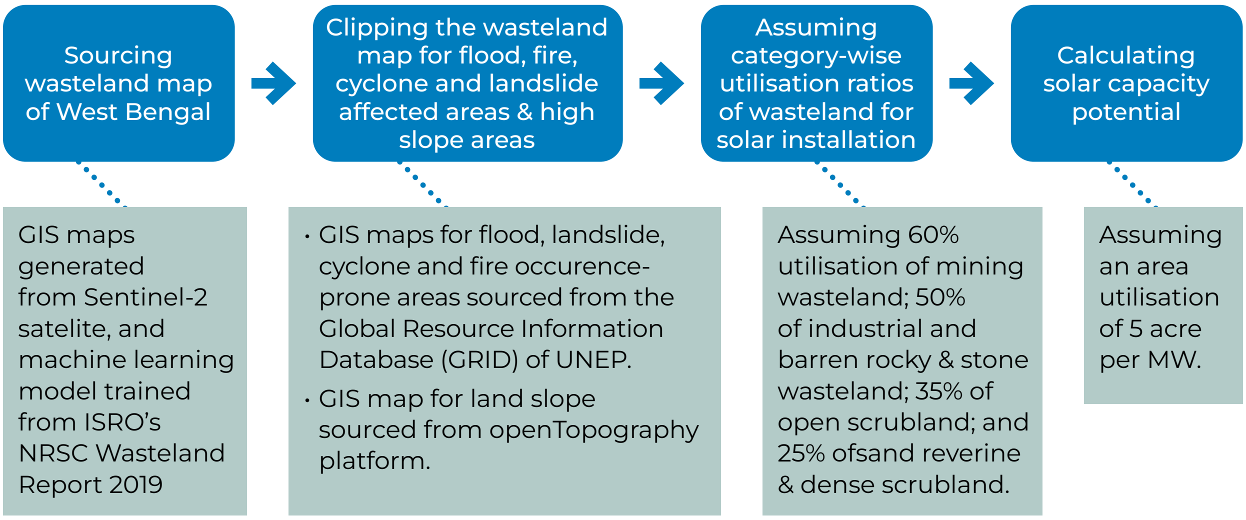
will be the previously created mosaic layer. Additionally, a reference layer for annotation, which consists of the supervised classification vector output, has been utilized. This setup enables precise and effective training of the models by leveraging the detailed spatial information provided by the mosaic and the accuracy of the classification vectors.

Step 7 - Training of Machine Learning Model: The pixel classification machine learning model has been trained using the ArcGIS Deep Learning Toolset, with the datasets created for classifying wasteland areas.

Step 8 - Model Refinement: The Pixel Classifier Model available through the ArcGIS Deep Learning Toolset, has been employed for model refinement. The input raster layer will be the mosaicked Sentinel-2 layer, which provides a comprehensive view of the terrain. Once the base model is created, testing and fine-tuning has been conducted to enhance accuracy. This iterative adjustment process will continue until saturation is reached, where further adjustments no longer yield significant improvements in model performance. This method ensures the model's maximum effectiveness in analysing and interpreting satellite imagery.

It is important to note that, based on previous outputs for Land Use and Land Cover (LULC) products, an accuracy ranging from 85% to over 90% is typically achieved. This level of accuracy is influenced by multiple factors, including the quality of the available satellite imagery for specific regions. A significant factor affecting this quality is cloud cover, which can obscure the satellite's view and impact the precision of imagery analysis.

Figure 2.1: Ground-mounted solar potential reassessment methodology



Source: iFOREST assessment

Potential reassessment

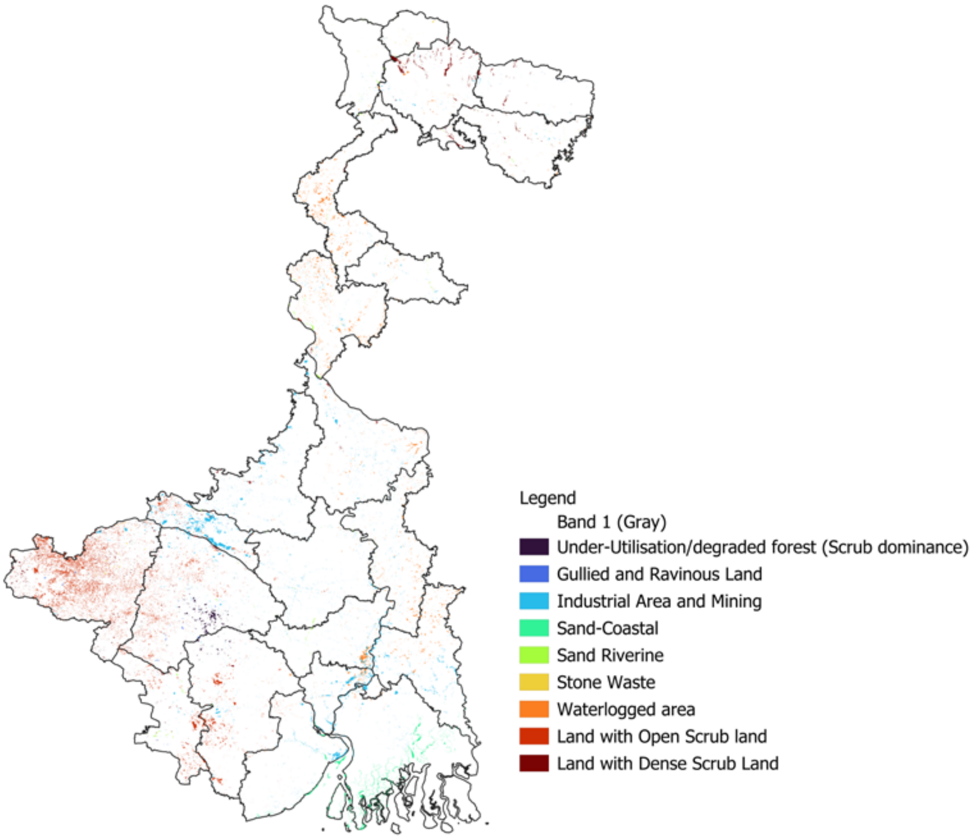
West Bengal is the thirteenth largest state in India, spanning over 88,752 sq. km. According to India's Wasteland Atlas 2019, only 1.87% of its landmass is designated as wasteland.

Based on Sentinel-2 satellite imagery and machine learning model, iFOREST mapped a wasteland area of about 1,725 sq. km in West Bengal. This is categorised across ten subcategories, of which more than 50 per cent is open scrubland, followed by 15 per cent dense scrubland and 9.8 per cent sand coastal. Industrial and mining wasteland also account for a significant share of the total wasteland with 8.3% and 4% share, respectively.

Following the mapping and identification of wastelands in West Bengal, the wasteland was analysed for exposure to flooding, landslides, cyclones and fire density which was deemed unsuitable for solar PV installations and was clipped from the feasible area for ground-mounted solar PV installation. From the 1,725 sq. km of available wasteland area in West Bengal, about 9.32 sq. km of area is removed for solar potential consideration due to high flooding probability, 15.62 sq. km is removed due to high landslide probability, 221.80 sq. km is removed due to high fire probability and another 133.73 sq. km is removed due to high cyclone probability.

Further, nearly 11.52 sq. km of the clipped wasteland area (after clipping floods, landslides, cyclones and fires) is removed for solar installation consideration due to the high slope.

Map 2.2: Wasteland map of West Bengal



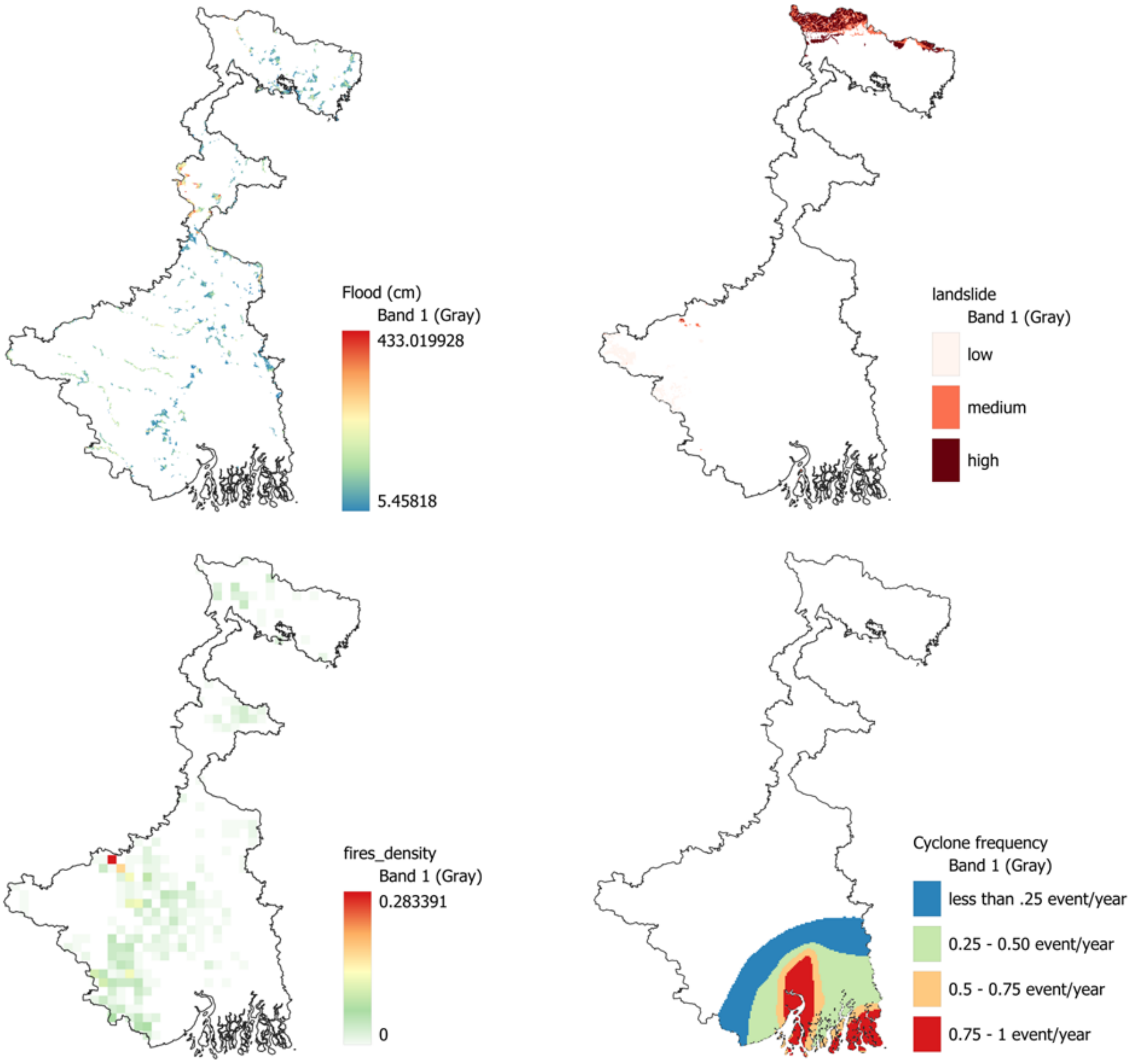
Source: iFOREST

Table 2.2: Wasteland categories in West Bengal

Type	Area (sq km)	Share (%)
Industrial wasteland	137.44	8.3
Mining wasteland	66.07	3.99
Sand riverine	50.97	3.08
Barren rocky and stone waste	11.19	0.67
Land with dense scrub	254.34	15.36
Gullied and ravenous land (medium)	12.77	0.77
Waterlogged area	79.29	4.79
Land with open scrub	883.41	53.37
Under-utilization/degraded forest (scrub) dominance)	66.77	4.03
Sand-coastal	162.73	9.83
Total wasteland	**1,725.02**	
Total area	**88,752**	

Source: iFOREST estimates based on Sentinel-2 satellite imagery

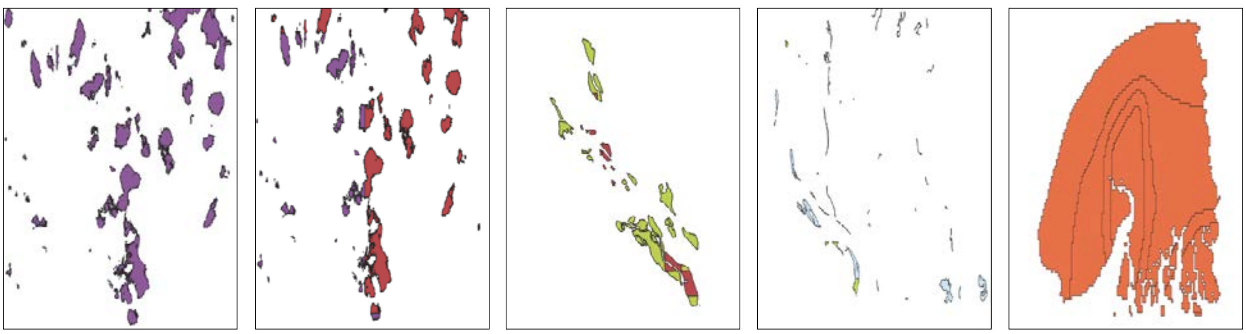
Map 2.3: Wasteland map clipped for undesired conditions



Source: iFOREST assessment

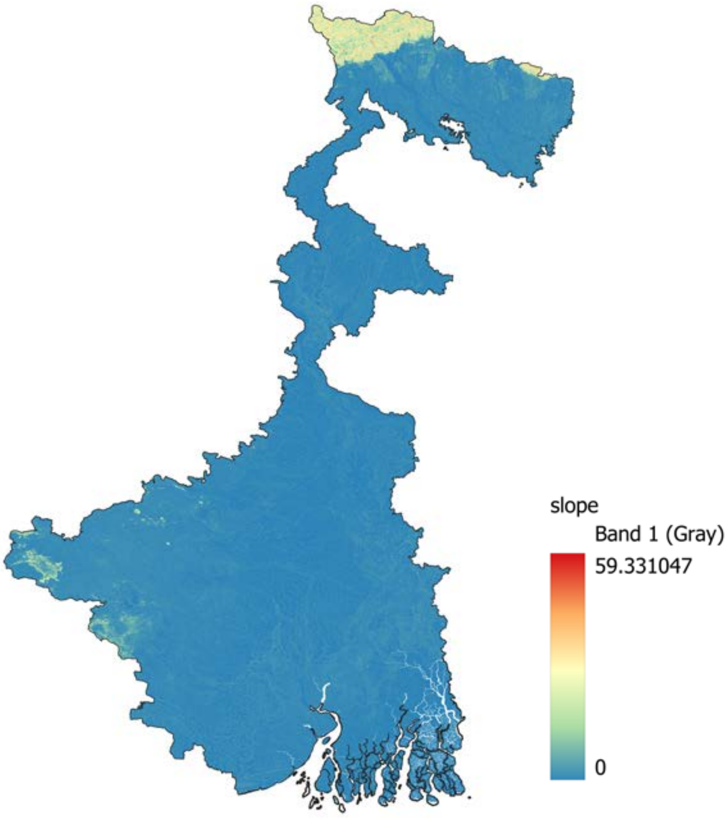
Map 2.4: Reference image for flood, landslide, fire density and cyclone prone clipped area

Total wasteland area → Wasteland area clipped for flood prone area → Clipped wasteland area clipped for landslide prone area → Wasteland area clipped for fire occurance area → Clipped wasteland area clipped for cyclone prone area



Source: iFOREST Assessment

Map 2.5: Clipping for high slope area



Source: iFOREST assessment

After mapping and analysing the wasteland in West Bengal, and excluding parcels with undesirable properties, five specific wasteland categories were identified as suitable for ground-mounted solar projects. These categories include barren rocky land, scrubland, mining/industrial wasteland, sandy areas, and degraded pasture/grazing land. Together, these categories account for 1,403.44 sq. km of wasteland, of which 1,101.45 sq. km of area remains available for consideration after clipping. Notably, under this analysis, approximately 63% of the total wasteland in the state is deemed unsuitable for ground-mounted solar projects.

- Post clipping, open scrublands are the largest available wasteland category with a land area of 758.56 sq. km. These lands are characterized by shallow, skeletal soils and arid conditions with low vegetation cover. In this study, 35% of the scrubland was considered for solar installation due to its relative ecological significance.
- Dense scrubland is the second largest wasteland category with 193.16 sq. km of clipped wasteland area. About 25% of this land type is assumed to be utilized for solar installations due to higher ecological sensitivity.
- Industrial and mining wastelands, which are dump lands for mining debris or industrial waste, constitute the next highest subcategory with 57.83 sq. km and 50.95 sq. km of clipped land area, respectively. A high utilization proportion of 50% to 60% is assumed for this category.
- Sandy areas, often found within river floodplains as sand sheets or sandbars, or as inland dunes shaped by wind, constitute 33.84 sq. km of the clipped wasteland area. A quarter of the available land is assumed to be utilized for solar development, due to higher ecological sensitivity.
- Barren rocky and stone wastelands constitute the smallest portion of the clipped wastelands in West Bengal with a 7.06 sq. km area. These are land patches devoid of vegetation and soil cover with exposed rock surfaces. Of these, 50% is assumed to be available for utilization for solar panel installations.

Table: 2.3: Wasteland category-wise ground-mounted solar installation potential

Usable wasteland category	Total area (sq. Km)	Area after clipping for flood, landslide, fire dense area & slope (sq. km)	Assumed land available for solar (sq. km)	Estimated potential (MW)
Industrial wasteland	137.44	57.83	28.91	1,429.23
Mining Wasteland	66.07	50.95	30.57	1,510.94
Sand Riverine	50.97	33.84	8.46	418.22
Barren rocky and stone waste	11.19	7.06	3.53	174.68
Land with dense scrub	254.34	193.16	48.29	2,386.65
Land with open scrub	883.41	758.56	265.59	13,121.23
Total	1,403.44	1,101.45	385.28	19,040.98

Note: Assuming 60% utilization of mining wasteland; 50% of industrial and barren rocky & stone wasteland; 35% of open scrubland; and 25% of sand riverine & dense scrubland.
Source: iFOREST Assessment

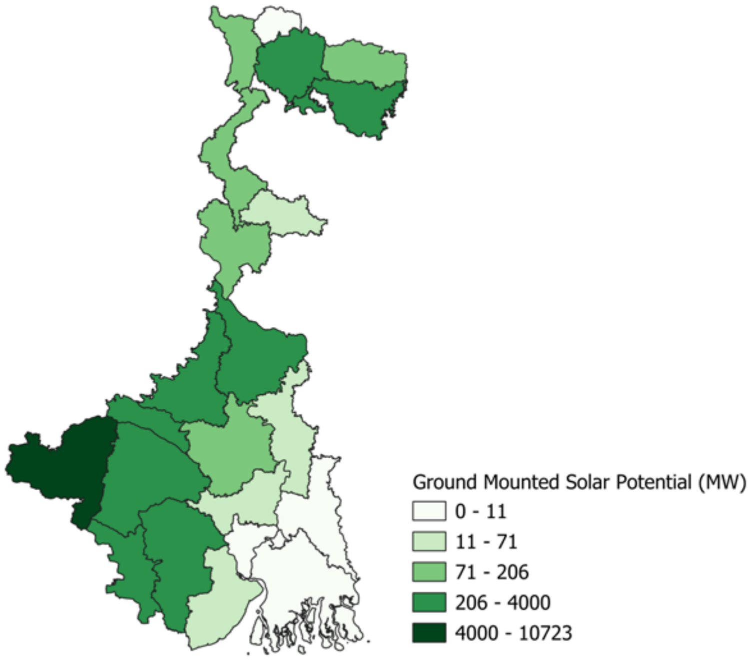
Based on the assumed utilisation ratios, 385 sq. km of wasteland is estimated to be available across the six wasteland categories for ground-mounted solar installations, capable of supporting 19,041 MW of solar capacity.

Nearly 69% of the assessed potential is concentrated in open scrublands, followed by 13% in dense scrubland. Industrial and mining wastelands account for 8% share each, while sandy areas and barren rocky land account for 2% and 1% share respectively.

District-wise, 56% of the assessed potential is concentrated in Puruliya due to the high availability of open scrubland. This is followed by Bankura and Paschim Bardhhaman districts which account for 13% and 7% of the assessed potential. Birbhum, Murshidabad and Jhargram districts each account for 4% share.

Significant solar capacity can be set up on mining and industrial wastelands in six key districts – Paschim Barddhaman (921 MW), Birbhum (720 MW), Murshidabad (593 MW), Bankura (289 MW), Puruliya (199 MW), and Purba Barddhaman (151 MW).

Map: 2.6: Ground-mounted solar potential distribution in West Bengal



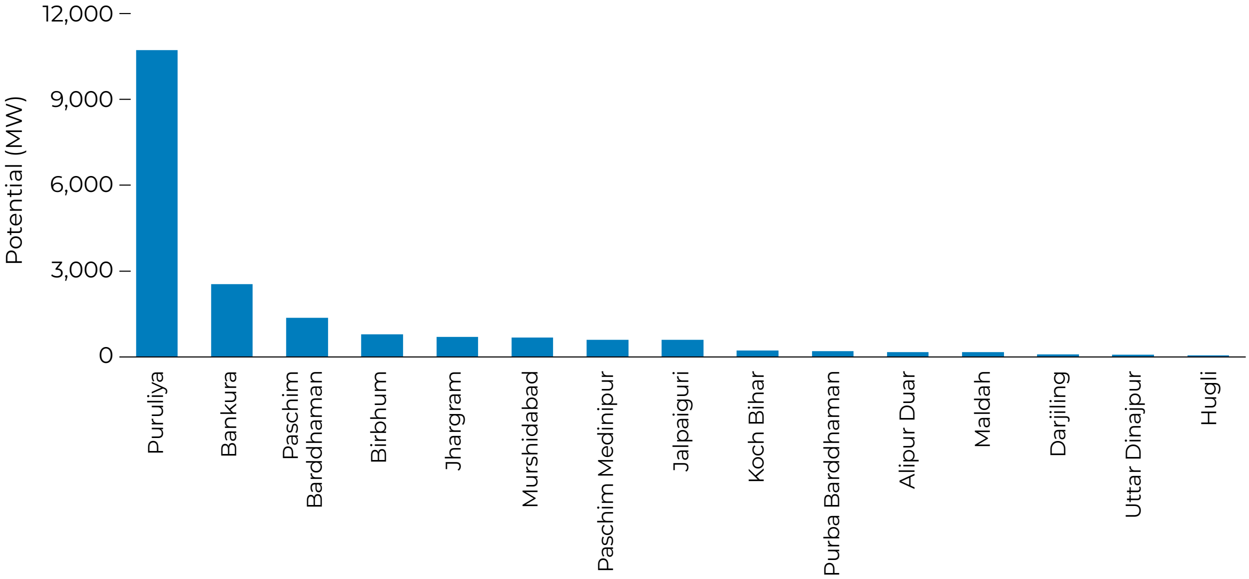
Source: iFOREST

Table: 2.4: District-wise estimated potential for ground-mounted solar across various land categories (MW)

District	Industrial Wasteland	Mining Wasteland	Sand Riverine	Barren rocky and Stone Waste	Land with Dense Scrub Land	Land with Open Scrub land	Potential
Alipur Duar	-	-	-	-	167	-	167
Bankura	201	88	20	2	227	2,007	2,546
Birbhum	145	575	16	-	56	-	792
Dakshin Dinajpur	-	-	30	-	-	-	30
Darjiling	3	-	35	-	47	-	85
Haora	-	-	-	-	-	-	-
Hugli	48	-	6	-	-	-	54
Jalpaiguri	-	-	7	-	586	-	593
Jhargram	-	-	32	-	68	603	703
Kalimpong	-	-	3	-	6	-	9
Koch Bihar	-	-	52	-	174	-	226
Kolkata	-	-	-	-	-	-	-
Maldah	-	-	119	-	43	-	162
Murshidabad	499	94	2	-	78	-	673
Nadia	-	-	22	-	-	-	22
North Twenty-Four Parganas	-	-	-	-	-	-	-
Paschim Barddhaman	173	748	-	-	87	359	1,367
Paschim Medinipur	2	-	-	-	36	562	600
Purba Barddhaman	151	-	31	-	-	19	201
Purba Medinipur	14	-	-	-	-	-	14
Puruliya	194	5	3	173	777	9,571	10,723
South Twenty-Four Parganas	-	-	-	-	-	-	-
Uttar Dinajpur	-	-	40	-	35	-	75
Total	1,429	1,511	418	175	2,387	13,121	19,041

Source: iFOREST Assessment

Figure 2.2: Top 15 districts for estimated ground-mounted solar potential



Source: iFOREST Assessment

2.2 High-potential wasteland clusters

From the perspective of project development, large clusters of wasteland parcels were identified using the processed wasteland data. In the absence of large consolidated wasteland pieces in West Bengal, a clusters-based approach can help capitalize on economies of scale. Along with wasteland distribution, the analysis also considers the distance of these clusters from existing substations to evaluate high-priority clusters for project development. The distance of each cluster from the nearest substations was mapped and calculated using data from OpenStreetMap[9], with further verification conducted via Google Earth.

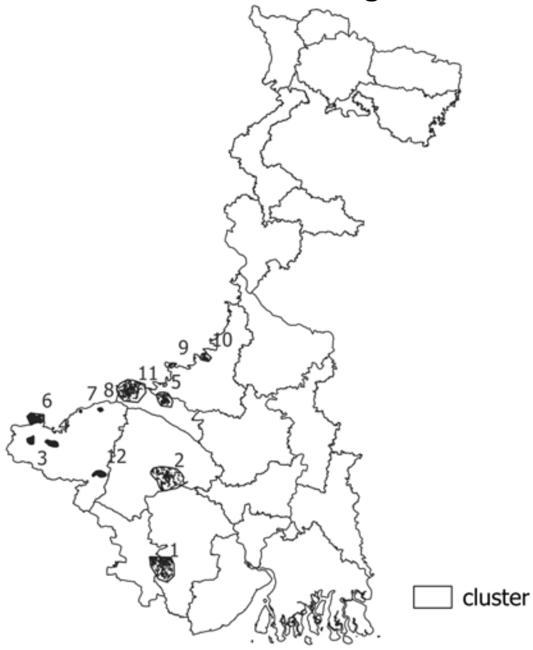
This approach led to the identification and shortlisting of 12 major clusters aggregating an area of 215.34 sq. km across seven districts of Puruliya, Birbhum, Paschim Bardhaman, Jhargram, and Paschim Medinipur. After accounting for the wasteland category-wise utilisation proportion, the identified area of 21.32 sq. km can support a solar capacity of 1,054 MW. However, for these land parcels, a higher level of utilization can also be prioritized.

Largest cluster is identified in Paschim Barddhaman & Birbhum district, comprising 12 land parcels of industrial wasteland, 5 parcels of mining wasteland, 2 parcels of sand riverine, and 21 parcels of land with dense scrubland. This cluster is capable of supporting 641.45 MW of solar capacity at an estimated CUF of 24.6%. This cluster also has proximity to an existing substation.

The second largest cluster is also focused on mining wasteland. Located in Birbhum district, this cluster includes 12 parcels of mining wasteland and can support 194 MW solar capacity at 24.26% CUF.

In addition, five land clusters are identified that can support 86 MW to 13 MW solar capacity, and another five clusters are identified with the potential of under 10 MW. Aggregation models can be designed and implemented to improve the techno-economic feasibility of such projects for development.

Map 2.7: Major wasteland clusters in West Bengal



Source: iFOREST assessment

Table 2.5: Largest wasteland clusters and their potential in West Bengal

Sl. no	District	Longitude	Latitude	Potential (MW)	Distance from substation (km)	CUF (%)	No of Parcel across wasteland categories
1	Jhargram & Paschim Medinipur	87.21738	22.2097	12.93	8.4	24.74	7 parcels of land with dense scrub land, 229 parcels of land with open scrub land
2	Bankura	87.2617	23.01133	6.44	6.37	24.75	3 parcels of land with dense scrub land, 4 parcels of land with open scrub land
3	Puruliya	86.03961	23.34563	3.14	13.24	25.39	78 parcels of land with dense scrub land, 24 parcels of land with open scrub land
4	Puruliya	86.22927	23.31875	7.39	7.72	25.36	3 parcels of sand riverine, 157 parcels of land with dense scrub land, 86 parcels of land with open scrub land
5	Paschim Barddhaman & Birbhum	87.23306	23.71089	641.45	1.27	24.6	12 parcels of industrial wasteland, 5 parcels of mining wasteland, 2 parcels of sand riverine, 21 parcels of land with dense scrub land
6	Puruliya	86.08251	23.54298	13.06	32.76	25.31	1 parcel of land with dense scrub land, 2 parcels of barren rocky and stone waste, 57 parcels of land with dense scrub land, 205 parcels of land with open scrub land
7	Puruliya	86.48247	23.60649	26.54	0.82	25.08	1 parcel of land with dense scrub land, 7 parcels of land with dense scrub land, 4 parcels of land with open scrub land
8	Puruliya	86.65936	23.62071	86.72	0	25.09	1 parcel of land with dense scrub land,16 parcels of land with open scrub land
9	Birbhum	87.29962	24.01706	0.52	26.36	24.56	5 parcels of land with dense scrub land
10	Birbhum	87.59752	24.08687	193.64	13.79	24.26	12 parcels of mining wasteland
11	Paschim Barddhaman	88.01866	25.88663	59.21	4.14	24.71	11 parcels of industrial wasteland, 2 parcels of mining wasteland, 55 parcels of land with dense scrub land, 237 parcels of land with open scrub land
12	Puruliya	86.6531	23.04734	2.84	20.47	25.27	3 parcels of land with dense scrub land, 100 parcels of land with open scrub land

Source: iFOREST Assessment

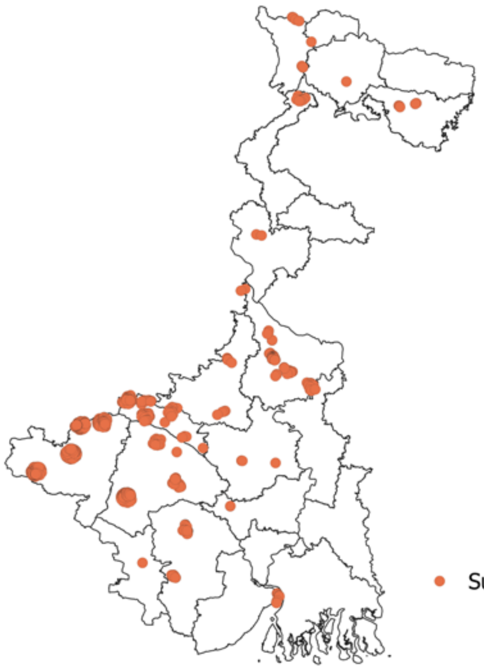
2.3 Wasteland parcels around existing substations

Building on the identification of major wasteland clusters suitable for ground-mounted solar projects, an additional analysis was conducted to identify wasteland parcels located near existing substations. These are particularly advantageous for solar project development (from a techno-commercial perspective) due to their proximity to established transmission infrastructure. Solar projects situated close to substations can significantly reduce costs by eliminating the need for additional transmission infrastructure.

For this, clipped wasteland parcels within a 5-km radius of 38 major transmission substations in West Bengal were identified and mapped. A total of 121.98 sq. km of wasteland was mapped. After accounting for the wasteland category-wise utilisation proportion, the identified area of 46.13 sq. Km can support a solar capacity of 2280.13 MW of solar capacity (assuming 100% land utilization within the identified wasteland parcels).

The assessment identified several high-capacity project locations, including three locations that can support capacities of over 350 MW, five locations that can support 100 MW to 130 MW, and two locations that can support 50 MW to 75 MW capacities.

Map 2.8: Wasteland parcels around existing substations



Source: iFOREST assessment

Table 2.6: Wasteland clusters for solar development around key substations in West Bengal

Sl. no	District	Latitude	Longitude	Voltage (kV)	Total usable land (sq. m)	Potential (MW)	CUF (%)
1	Darjiling	88.3345	27.1065	220	39,201.56	1.94	18.03
2	Kalimpong	88.45946	26.92592	220	212.51	0.01	18.05
3	Bankura	86.87071	22.96923	132	20,53,154.62	101.47	23.57
4	Darjiling	88.41957	26.67634	220;132	4,78,950.50	23.67	20.21
5	Paschim Barddhaman	86.8709	23.82246	400;220	20,56,634.61	101.64	23.25

Table 2.6 continued

Sl. no	District	Latitude	Longitude	Voltage (kV)	Total usable land sq. m	Potential (MW)	CUF (%)
6	Paschim Barddhaman	87.02208	23.67344	132	4,75,445.65	23.5	23.11
7	Paschim Barddhaman	87.35048	23.52594	400;220;132	10,56,561.77	52.22	22.96
8	Bankura	87.1343	23.46542	220	5,03,072.54	24.86	23.21
9	Bankura	87.28613	23.3997	132	7,005.44	0.35	23.16
10	Puruliya	86.39063	23.34672	220	95,09,798.73	469.98	23.86
11	Bankura	87.31372	23.10085	220	2,12,785.54	10.52	23.19
12	Puruliya	86.39063	23.34672	132	95,20,196.15	470.5	23.86
13	Koch Bihar	89.39625	26.41118	25	51,330.82	2.54	20.64
14	Murshidabad	88.27267	24.08278	132	4,70,629.87	23.26	22.39
15	Murshidabad	88.12423	24.04551	400;220;132	63,879.04	3.16	22.6
16	Birbhum	87.78169	24.15746	132	2,30,382.59	11.39	22.65
17	Hugli	87.71882	22.88818	400;220;132	16,563.04	0.82	22.99
18	Purba Barddhaman	87.87535	23.27438	132	1,94,867.90	9.63	22.85
19	Paschim Medinipur	87.29449	22.31932	132	8,08,833.80	39.97	23.07
20	Puruliya	86.09146	23.19317	400	25,03,137.43	123.71	23.96
21	Paschim Barddhaman	87.04558	23.78367	132	2,72,149.65	13.45	23.21
22	Purba Barddhaman	88.15101	23.26622	220	25,461.55	1.26	22.73
23	Paschim Barddhaman	87.54922	23.43528	132	5,043.67	0.25	23.04
24	Birbhum	87.70336	23.68535	132	99,918.44	4.94	22.94
25	Paschim Barddhaman	87.20138	23.58394	400	13,547.63	0.67	22.97
26	Murshidabad	88.44116	23.92552	132	2,83,977.49	14.03	22.34
27	Purba Medinipur	88.16911	22.09624	132	13,956.10	0.69	22.68
28	Murshidabad	88.12902	24.19823	400	3,11,395.13	15.39	22.51
29	Puruliya	86.66484	23.62055	400	25,99,722.51	128.48	23.54
30	Uttar Dinajpur	88.37299	26.41727	132	34,836.61	1.72	20.54
31	Murshidabad	87.89732	24.76832	400;220	15,31,714.45	75.7	22.19
32	Puruliya	86.46963	23.59986	220;132	21,57,883.23	106.64	23.6
33	Koch Bihar	89.19536	26.34262	132	51,578.16	2.55	20.61
34	Murshidabad	88.54487	23.89374	132	20,004.46	0.99	22.28
35	Murshidabad	88.10906	24.37025	400;220	3,43,514.25	16.98	22.37
36	Paschim Medinipur	87.37982	22.69091	765;400	8,02,606.03	39.67	23.12
37	Birbhum	87.27568	23.7103	132	72,54,838.05	358.54	23.1
38	Jhargram	87.01593	22.39396	33;11	62,174.73	3.07	23.33
Total					**46.13**	**2,280.13**	

2.4 Floating Solar

In addition to reassessing the potential for ground-mounted solar installations, it is also crucial to explore the potential for land-neutral solar technologies, particularly on man-made reservoirs. The technology offers significant opportunities for solar capacity enhancement in regions with low availability of large wasteland parcels, with the added benefits of creating hybrid RE plants (in combination with hydropower) and potentially reducing water evaporation losses in many cases.

According to data from the National Register for Large Dams (NRLD) published by the Central Water Commission (CWC) of the Ministry of Jal Shakti, West Bengal is home to 30 large dams.[10] Of these, 28 dams were considered for evaluating floating solar potential, based on factors such as water availability and the accessibility of relevant data. These dams provide significant potential for floating solar installation even at low utilization assumptions.

Assessment methodology

A three-step methodology is adopted for the estimation of the floating solar potential of West Bengal based on secondary data sets available for dams focusing on four key parameters – purpose, age, depth and area of the reservoir.

Step 1: Comprehensive identification of suitable waterbodies for floating solar:

The identification of waterbodies suitable for floating solar installations involved utilizing multiple authoritative sources to ensure comprehensive coverage across all categories of waterbodies. Primary data was sourced from the CWC's NRLD (2019), which provided an extensive inventory of waterbodies, particularly large reservoirs and dams. This data was further cross-verified using ISRO's Bhuvan Water Bodies Information System (India-WBIS), a satellite-based resource that offers detailed information on waterbody extents and characteristics[11]. The portal provided key information regarding the dams, including water availability, water spread area, reservoir area, and depth. Additionally, Google Earth was employed to visually inspect and validate the identified waterbodies, ensuring accuracy and completeness in the dataset.

Step 2: Filtering and categorization of waterbodies:

The datasets were then filtered based on specific criteria to refine the selection of waterbodies most suitable for floating solar projects. The waterbodies were categorized according to several key factors, including their utilization type, depth, age, and the area of the reservoir. These categories were essential in assessing the feasibility and potential efficiency of floating solar installations. Each category was evaluated to determine its suitability for floating solar based on these attributes, which influence both the technical feasibility and economic viability of solar deployment on water surfaces.

In this process, given industry practices, reservoirs with a spread area below 4,000 sq. km and with depths of less than 3 m were considered unsuitable for floating solar installations. Also, very old dams of over 50 years of age were omitted from the study, considering higher environmental impact, as they inhabit higher degrees of flora and fauna.

Step 3: Calculation of area available for floating solar installation:

For each shortlisted category of waterbodies, the reservoir area was assessed to calculate the total area available for floating solar installation. The calculation was based on category-wise utilization assumptions, which considered the specific characteristics of each waterbody type, such as the proportion of the reservoir area that could be effectively utilized for solar panels without compromising other critical functions of the waterbody (e.g., irrigation, drinking water supply, or flood control).

Developing on the reservoir conditions such as depth, area, age and usage of reservoirs, three utilization scenarios of high, medium and low were assumed. The utilization varied across reservoir types based on the purpose. While a reservoir level assessment is important to determine the actual area available for floating solar deployment, the utilization assumptions provide an indicative picture across multiple scenarios.

The potential was then assessed based on the utilization assumption for each dam category across the three scenarios and age classification, and an area requirement of 10,117 sq. m for one MWp.[12]

Table 2.7: Sources and tools used for estimating floating solar potential

Data/Parameter	Source/Tool
Reservoir data, 2019	CWC, NRLD
Reservoir mapping	Google earth
Water occurrence, spread area and water level	IWRIS, ISRO Bhuvan WBIS
Waterbody utilization scenario	SIA assumptions

Table 2.8: Reservoir-type-based utilization scenario assumption for floating solar PV installation

Reservoir purpose	Low utilization scenario	Medium utilization scenario	High utilization scenario
Irrigation and water supply	5%	10%	20%
Irrigation	10%	25%	50%
Flood control, hydroelectric, irrigation and water supply	1%	2%	2%
Hydroelectric	3%	5%	10%
Water supply	10%	25%	50%
Irrigation, flood control	5%	10%	10%
Irrigation, hydroelectric, navigation	2%	5%	10%
Irrigation, hydroelectric	2%	10%	10%
Irrigation, hydroelectric, water supply	2%	5%	5%
Irrigation, pisciculture	5%	10%	20%
Irrigation, pisciculture, water supply	5%	10%	20%
Irrigation, pisciculture, water supply, hydroelectric	2%	5%	5%
Irrigation, earth fill embankment	10%	25%	50%
Irrigation, hydroelectric, water supply, tourism, flood control	2%	5%	5%

Source: iFOREST assessment

Potential assessment

Of the 30 dams existing in West Bengal, 25 dams are of medium age (20 to 50 years), while 3 dams are of young age (0 to 20 years), and 2 dams are (50 to 100 years). There are no very old dams (over 100 years) or dams under construction. As for depth, 13 dams are of low depth (10 to 15 m), 13 dams are of medium depth (15 to 30 m) and 4 dams are of high depth (30 to 100 m). Thus, all dams are considered in the assessment (barring one for which data was not available and another that was close to 100 years old).

Given the utilization assumptions across various reservoir types, the floating solar PV potential is estimated to be 715 MW in the low scenario, 1,784 MW in the medium scenario and 3,567 MW in the high scenario.

Most of the assessed potential capacity is in the Bankura district (with a high scenario potential of 1,986 MW across three reservoirs), followed by the Puruliya district (with a high scenario potential of 1,225 MW across 21 reservoirs). The high potential of Bankura district is due to the presence of Kangsabati Dam that can potentially host a large-scale floating solar plant of 1,790 MW.

Table 2.9: Number of reservoirs in West Bengal categorized by age and depth

	Young age (0 to 20 years)	Middle age (20 to 50 years)	Old age (50 to 100 years)	Very old age (> 100 years)	Under construction	Total
Very low depth (3 to 10 m)	0	0	0	0	0	0
Low depth (10 to 15 m)	1	12	0	0	0	13
Medium depth (15 to 30 m)	0	13	0	0	0	13
High depth (30 to 100 m)	2	0	2	0	0	4
Very high depth (>100m)	0	0	0	0	0	0
Total	**3**	**25**	**2**	**0**	**0**	**30**

Source: iFOREST

Table 2.10: Top ten potential reservoir sites for floating Solar installation

Name Of Water Body	District	Type	Area (1000 sq m)	Effective area (1000 sq m)			Potential (MWp)		
				Low	Medium	High	Low	Medium	High
Kangsabati Kumari	Bankura	Irrigation	36,250	3625	9063	18125	358	896	1,792
Hinglow	Birbhum	Irrigation	6,480	648	1620	3240	64.1	160	320
Bandhu Extension	Puruliya	Irrigation	4754	475	1189	2377	47	117	235
Hanumata	Puruliya	Irrigation	2,126	213	532	1063	21	52.5	105
Tatko	Puruliya	Irrigation	2028	203	507	1014	20.1	50.1	100
Maliarajore	Bankura	Irrigation	1984	198	496	992	19.6	49	98.1
Sali	Bankura	Irrigation	1951	195	488	975.5	19.3	48.2	96.4
Patloi	Puruliya	Irrigation	1820	182	455	910	18	45	90
Kumari	Puruliya	Irrigation	1783	178	446	891.5	17.6	44.1	88.1
Saharajore	Puruliya	Irrigation	1720	172	430	860	17	42.5	85

Source: iFOREST assessment

2.5. Conclusion

West Bengal, with over 300 days of sunshine annually and an average solar radiation of 4.60 kWh per square meter, has moderate solar resources. However, with the growing requirement of solar capacity addition in the coming decades, the state's solar resources will become important. A strategic approach can be adopted to explore the wastelands available in the state, focusing on land patches available in clusters and near existing substations. Additionally, significant capacities can be developed by utilizing land-neutral solar PV technologies, including large- to small-scale deployments of solar PV projects.

3. Wind

Assessing and identifying the availability of high-quality wind sites is a fundamental prerequisite for accurately estimating the wind energy potential of a region. This assessment involves evaluating several key parameters, including wind speed, direction, turbulence, air density, and shear, among other parameters. In the case of West Bengal, the overall wind energy generation potential is moderate due to relatively higher wind speeds, with several identified locations offering conditions suitable for wind energy development.

In India, wind resource assessment is being undertaken by the National Institute of Wind Energy (NIWE) of the Ministry of New and Renewable Energy (MNRE). The evaluation is based on an advanced meso-micro coupled numerical wind flow model, which is supplemented by data from 406 actual measurement sites across the country. This approach also considers multiple land use and environmental factors, to ensure an accurate estimation of the wind energy potential.

At present, the total installed wind capacity in India stands at 47 GW, with no capacity installed in West Bengal so far[13]. According to NIWE's assessment, wind energy potential for West Bengal stands at 1,050 MW at 120m hub height with a major chunk of it (or 989 MW) coming from potential with 30% cultivable land usage[14]. Similarly, for the 150m hub height, the estimated wind potential is 1,281 MW, most of it coming from 30% cultivable land usage[15]. Overall, the assessed wind potential for West Bengal constitutes a minuscule fraction of less than 0.2% of India's total wind energy potential.

A focus on the state's wind energy potential is crucial at this stage as the best wind sites across the country become increasingly exhausted, and the techno-economic feasibility of moderate sites becomes increasingly enhanced.

Table 3.1: NIWE's wind energy potential assessment for West Bengal and India

Category	West Bengal (MW)	India (MW)
Potential at 120m hub height	1,050	695,508
• with 80% wasteland usage	27	340,112
• with 30% cultivable land usage	989	347,045
• with 5% forest land usage	34	8,351
Potential at 150m hub height	1281	1,163,856
• with 80% wasteland usage	28	544,448
• with 30% cultivable land usage	1208	607,288
• with 5% forest land usage	45	12,120

Source: NIWE

3.1 Assessment methodology

Initial scoping for wind resource assessment is done by identifying wind-rich areas using satellite data. This identification is done using publicly available wind resource maps available at Global Wind Atlas (GWA 3.1)[16]. The GWA 3.1 portal has been developed by the Technical University of Denmark (DTU Wind Energy) with support from the World Bank Group. It provides detailed data on wind power density and wind speed at multiple heights for all global locations. It is based on historical weather information and modelling, with an output resolution of 250 meters. The identified sites through the GWA 3.1 portal were further mapped on NASA's Shuttle Radar Topography Mission (SRTM) database[17] to filter areas that offer lower techno-commercial feasibility. The database provides a high-resolution digital topographic database of the earth.

The focus was on identifying areas with wind speeds greater than the threshold value of 5 m/s. Parallelly areas with high slopes (greater than 15 degrees), land prone to landslide due to precipitation (medium, and high frequencies), affected by frequent fires (with active fire density for the year 2022), and affected by frequent cyclones were clipped away. Thus, for estimation of wind energy potential at 100m and 150 m AGL, the clipped potential total area and the wasteland areas within the threshold wind speed (5 to 8 m/s) are identified across all districts.

The energy generation potential for the identified land areas was then assessed using a standard wind turbine model of GE 130 with a turbine diameter of 130 m, swept area of 13,273 sq. m and annual power generation of 28.032 GWh at air density of 1.225 kg/m^3. For spacing between wind turbines, a spacing density of 4.375 was considered and turbine spacing density i.e., the area required for each turbine including spacing between turbines was calculated using the formula – 4.375 x 130 m x 4.375 x 130 m to arrive at 323,476.6 sq. m. The methodology for annual power generation and spacing factor was adapted from similar studies attempting to estimate wind energy potential in India[18].

Table 3.2: Parameters for wind energy generation estimation

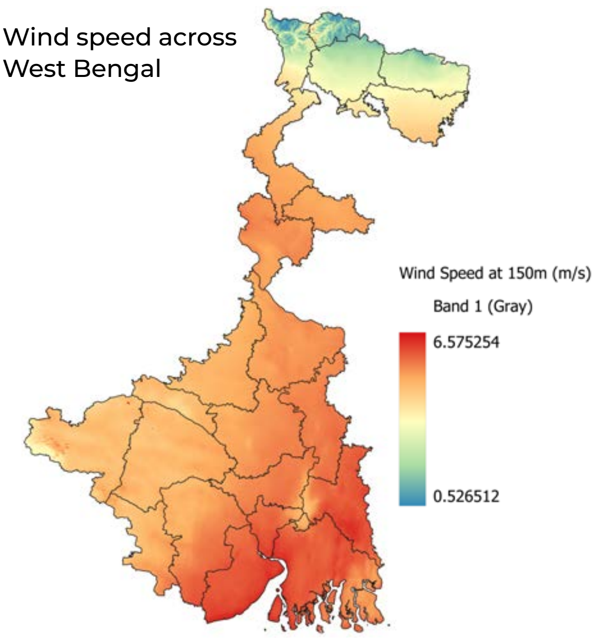
Model	GE 130
Diameter (m)	130
Swept area (Sq. m)	13273
Annual ideal power generation (GWh)	28.032
Air density (kg/m3)	1.225
Turbine spacing density (sq. m/turbine)	323476.6
Spacing factor	4.375

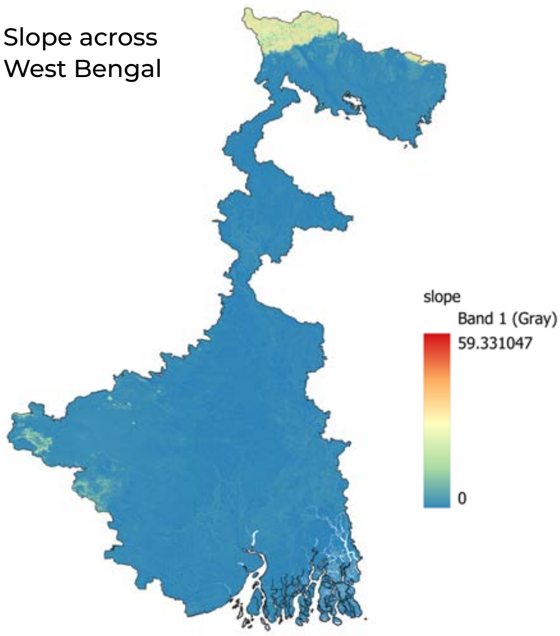
Source: Von Krauland, A. K., & Jacobson, M. Z. (2024). India onshore wind energy atlas accounting for altitude and land use restrictions and co-located solar. Cell Reports Sustainability

3.2 Potential re-assessment

Building on the wind resource map sourced from GWA 3.1, a total of 2,117 high wind speed sites (63 sites for 100 m hub height and 2,054 sites for 150 m hub height) were identified in West Bengal, each with an average wind speed greater than 5 m/s. This was done by analyzing the 10-year average wind speed data at 100 m and 150m above ground level (AGL). These sites were then mapped onto the SRTM database to filter out areas with steep slopes and high frequency of landslides, fires and cyclones.

Map 3.1: Identified wind sites and terrain for West Bengal





Source: iFOREST assessment

After filtering for climate risks and high slopes, nearly 1,990 sq. km of area was identified as high potential sites at 100 m AGL. About 93% of the identified area has an assessed wind speed of 5 to 6 m/s, while the remaining 7% has a wind speed of 6-7 m/s. Further, at 150 m AGL hub height, the potential area expanded to 2,300 sq. km. This includes 74% area at a wind speed of 5 to 6 m/s and the remaining 26% area at a wind speed of 6-7 m/s.

Table 3.3: Filtered area under threshold wind speeds in West Bengal

Wind Speed (m/s)	Area at 100 m AGL (sq. km)	Area at 150 m AGL (sq. km)
5 to 6	1,867.45	1,711.95
6 to 7	123.29	592.61
7 to 8	0	0
Total	1,990.74	2,304.56

*After filtering for high slopes and climate risks
Source: iFOREST estimates

The identified land area can potentially hold significant wind power generation capacity. At a hub height of 100 m AGL, an estimated 6,154 wind turbines can be installed, leading to a theoretical potential of 19.69 GW. Similarly, at a hub height of 150 AGL, 7,124 turbines can be installed leading to a potential of 22.79 GW. About 5.89 GW of potential is identified at high wind speeds of 6 to 7 m/s at a hub height of 150 m AGL.

Table 3.4: Estimated wind power potential across filtered areas with threshold speeds

Speed (m/s)	At the hub height 100 m			At the hub height 150 m		
	No. of turbines	Annual generation (GWh)	Potential (GW)	No. of turbine	Annual generation (GWh)	Potential (GW)
>5 and <6	5,773	22,612.47	18.47	5,292	20,729.56	16.93
>6 and <7	381	2,696.96	1.21	1,832	12,963.34	5.86
Total	**6,154**	**25,309.43**	**19.69**	**7,124**	**33,692.90**	**22.79**

Source: iFOREST estimates

Identifying the total area under threshold wind speed gives a broader sense of feasibility of wind energy installations in the state, as wind energy installations are considerably less sensitive to land categories and can be installed in non-wasteland areas (unlike solar projects which need to be prioritised over wastelands). However, owing to higher costs of land acquisition and overall ease of installation, estimating wind energy potential on wastelands is crucial.

Wind potential on wastelands

The wasteland area under the threshold windspeed of 5 m/s was calculated at 100 m and 150 m AGL, which was further processed for high slope, and high frequency of landslides, fires and cyclones. At a hub height of 100 m AGL, a total of 63 potential land parcels were identified, aggregating to an area of 12.92 sq. km. Further, a hub height of 150 m AGL, 2,054 potential land parcels were identified, aggregating to an area of 223.55 sq. km. This amounts to a wasteland-based wind energy potential of 115.2 MW and 1,676.8 MW at 100 m and 150 m AGL, respectively.

The majority of the wasteland-based wind energy potential is localized in a few districts in the southern and northern regions of the state. Of the assessed potential at 100 m AGL, four districts of Purba Medinipur, Nadia, North Twenty-Four Parganas, and Paschim Medinipur account for the entire estimated potential. However, the potential is more widespread at a higher hub height of 150 m AGL. Uttar Dinajpur accounts for the higher potential with a share of 20%, followed by Maldah with a 15% share, Paschim Medinipur and Murshidabad with a 12% share each, and Jhargram and South Twenty-Four Parganas with 10% share each.

Table 3.5: Wasteland area under threshold wind speed in West Bengal

Wind speed (m/s)	Wasteland area at 100 m AGL (sq. km)	No. of wasteland parcels at 100 m	Wasteland area at 150 m AGL (sq. km)	No. of wasteland parcels at 150 m
5 to 6	5.61	53	199.03	1,880
6 to 7	7.31	10	24.52	174
7 to 8	0	0	0	0
Total	12.92	63	223.55	2,054

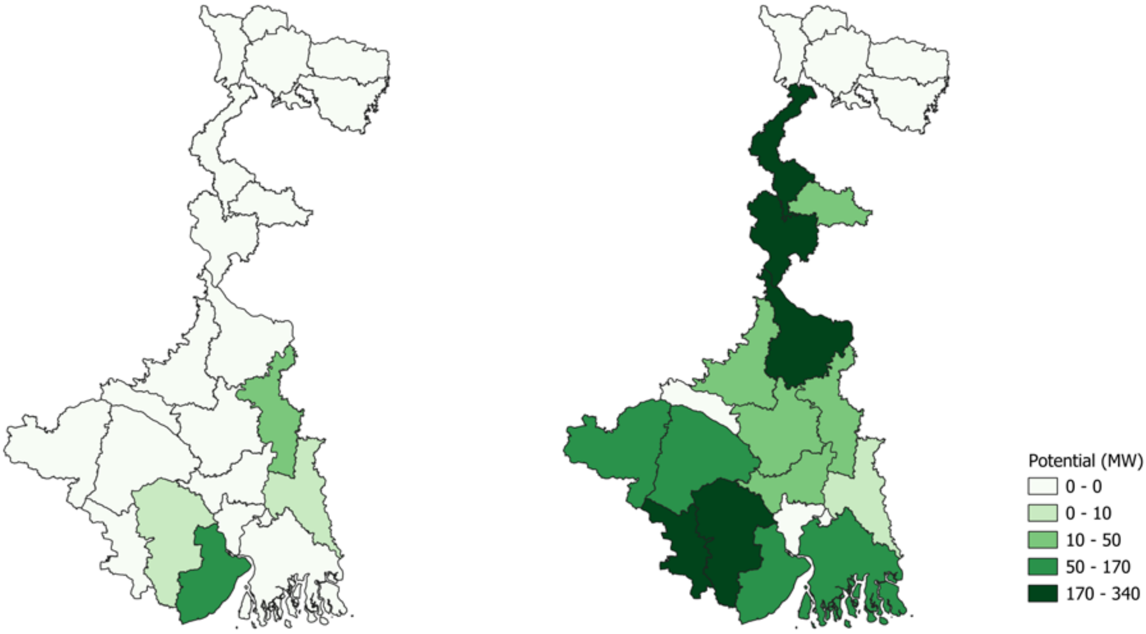
Source: iFOREST estimates

Table 3.6: District-wise wind energy potential at 100m and 150m AGL on wastelands

District	Across wasteland area	
	Potential at 100m (MW)	Potential at 150m (MW)
Bankura	0	48
Birbhum	0	9.6
Dakshin Dinajpur	0	12.8
Hugli	0	6.4
Jhargram	0	172.8
Maldah	0	256
Murshidabad	0	198.4
Nadia	9.6	32
North Twenty-Four Parganas	3.2	3.2
Paschim Medinipur	3.2	208
Purba Barddhaman	0	44.8
Purba Medinipur	99.2	102.4
Puruliya	0	83.2
South Twenty-Four Parganas	0	160
Uttar Dinajpur	0	339.2
Total Potential (MW)	**115.2**	**1,676.8**

Source: iFOREST estimates

Map 3.2: Distribution of wind energy potential in West Bengal at 100 m and 150 m AGL



Source: iFOREST estimates

High-potential wasteland parcels

To prioritize and rank wasteland parcels most feasible for wind energy installations, some of the largest wasteland parcels were also identified along with the available area and estimated annual generation potential. At 100 m AGL, seven potential land parcels were identified, with two larger parcels with the potential to set up 70.4 MW and 22.4 MW projects, which could operate at a CUF of over 21%. At, 150 m AGL, ten potential land parcels are identified, with a potential to set up wind power plants to 100 MW to 20 MW, with a CUF ranging from 28% to 14%.

Table 3.7: Leading wasteland parcels in West Bengal at 100m AGL

District	Area (sq. m)	No. of turbine	Average CUF (%)	Annual generation (GWh)	Potential (MW)
Purba Medinipur	7,046,230	22	21.15	150	70.4
Purba Medinipur	2,317,880	7	21.15	34	22.4
Nadia	1,061,384	3	13.55	11	9.6
Purba Medinipur	276,337	1	21.15	6	3.2
Purba Medinipur	201,924	1	21.15	7	3.2
North Twenty-Four Parganas	349,517	1	16.40	5	3.2
Paschim Medinipur	165,202	1	13.99	4	3.2

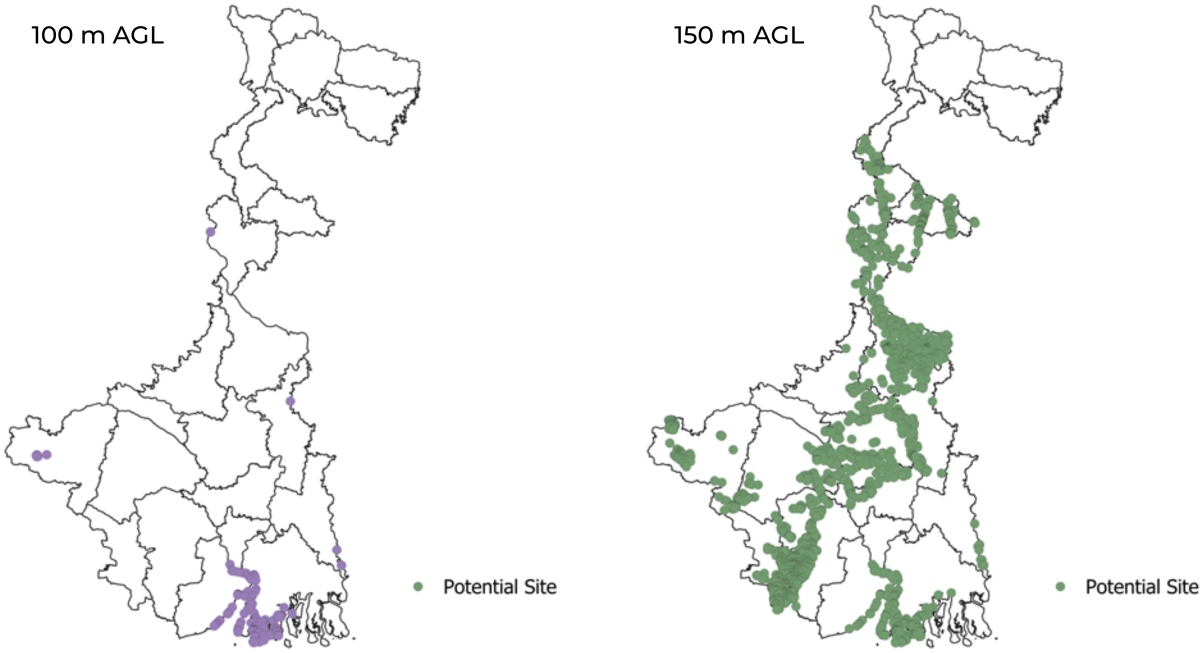
Source: iFOREST estimates

Table 3.8: Top ten wasteland parcels in West Bengal at 150 m AGL

District	Area (sq. m)	No. of turbine	Average CUF (%)	Annual generation (GWh)	Potential (MW)
Jhargram	10494400	32	15.78	132	102
Uttar Dinajpur	8171254	25	14.34	98	80
Purba Medinipur	7046230	22	28.14	180	70
Murshidabad	4118726	13	15.96	61	42
Paschim Medinipur	3331442	10	15.71	44	32
Murshidabad	2969051	9	15.96	35	29
Murshidabad	2791052	9	15.96	35	29
Maldah	2721307	8	16.27	34	26
Uttar Dinajpur	2529792	8	14.34	33	26
Purba Medinipur	2317880	7	28.14	51	22

Source: iFOREST estimates

Map 3.3: High potential wasteland parcels in West Bengal at 100 m and 150 m AGL



Source: iFOREST assessment

3.3. Conclusion

The present official estimate for wind power generation in West Bengal is limited to about 1,050 MW at 120 m AGL. Satellite-based data assessment points to a much higher potential of several gigawatts at higher hub heights. Even restricted to wastelands, multiple land parcels can be identified where utility-scale projects can be potentially set up. This provides a strong case for further ground-level assessment to be undertaken in the state to assess project bankability. This is potentially crucial as wind power is gaining much more significance in the energy mix as India inches towards a net zero scenario; as well as due to the best potential wind sites getting exhausted in the country and the focus gradually shifting to the development of moderate sites.

4. Biomass Energy

Biomass energy potential is mainly a factor of the quantum of surplus crop residue and its calorific value. Evaluating the energy potential from biomass depends on crucial factors including the extent of land under cultivation, cultivated crops and cultivation seasons.

In West Bengal, the cultivated area stands at about 5.5 million hectares (ha), comprising 62% of the total geographical area. About 54% of the cultivated area is irrigated and the cropping intensity is high at about 176%. The dominant soil types are acidic, saline and sodic, which are typically low in fertility. The important crops are rice, potato, mustard, pulses and jute.[19]

Agricultural production in West Bengal has been expanding over the past decade, creating a strong foundation for harnessing biomass for energy generation. From 2010-11 to 2020-21, food grains production in the state rose from 148.1 lakh metric tonne (MT) to 205.3 lakh MT. The state remains among the top rice producers in India, with rice output growing from 133.9 lakh MT to 169.06 lakh MT during the given period. Maize production also surged to 25.78 lakh MT, and productivity increased significantly to 7.14 tonnes per ha, due to new hybrid varieties and improved practices. Pulses production also grew to 4.42 lakh MT, up from 1.77 lakh MT, while oilseeds production rose to 11.12 lakh MT from 7.0 lakh MT[20].

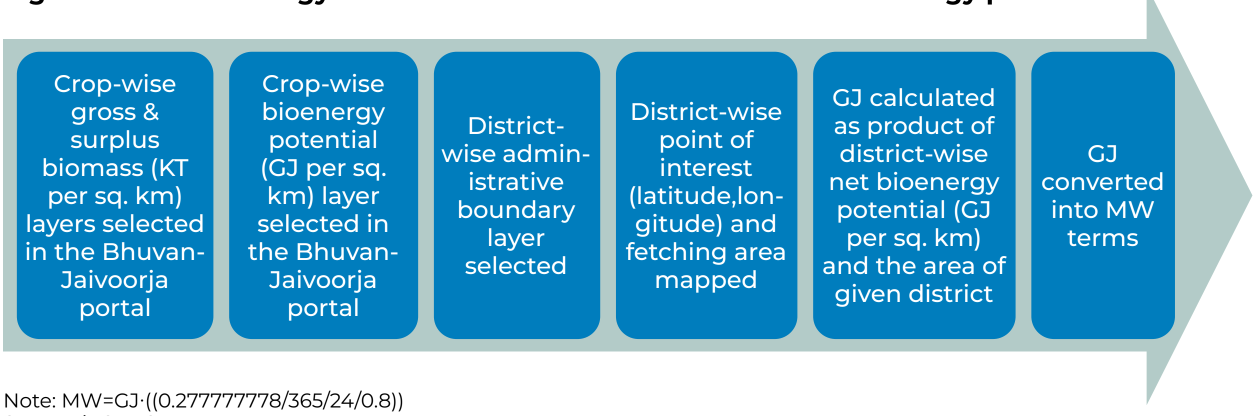
According to the Ministry of New and Renewable Energy (MNRE), the biomass power potential of West Bengal is estimated to be 1,591 MW. So far, about 22% of this potential has been harnessed with 348.36 MW of biomass-based capacity installed in the state as of March 2024. This comprises 300 MW of bagasse-based cogeneration, 43.52 MW of non-bagasse-based cogeneration and 4.84 MW of waste-to-energy off-grid generation[21].

However, with the expanding food grain production in the state, the potential of biopower generation is constantly expanding and needs reassessment based on updated datasets.

4.1. Reassessment methodology

The reassessment of biomass-based renewable energy generation potential was conducted using updated datasets on gross and surplus residue production sourced from the Bhuvan-Jaivoorja portal[22]. The portal has been developed by the Technology Information Forecasting and Assessment Council (TIFAC), Department of Science and Technology, and the National Remote Sensing Centre (NRSC), Indian Space Research Organisation (ISRO). The portal helps generate geospatial maps of surplus and gross residue potential of crops across all districts in India. Potential crop masks were built for each of the districts in the state using multi-temporal satellite data, which were then transformed into crop fractions at a resolution of 1 km grid based on the MODIS gross primary production (GPP) dataset. Subsequently, the surplus biomass data was converted into biomass energy potential using the heating value/calorific value specific to each crop residue.

Figure 4.1: Methodology for re-assessment of biomass-based bioenergy potential



Note: MW=GJ·((0.277777778/365/24/0.8))
Source: iFOREST

Table 4.1: Crop-wise productivity and heating value for crop residue-based bioenergy production

Crops	Yield (kg/ha)	Dryness factor (%)	Residue type	Heating value (MJ/kg)
Rice	2,730	0.86	Straw	15.54
			Husk	15.54
Wheat/Maize/Ragi	3,195	0.86	Straw	17.15
			Husk	17.39
Cotton	547	0.80	Stalk	17.40
			Husk	16.70
			Boll Shell	18.30
Sugarcane	72,268	0.83	Bagasse	20.00
			Top and leaves	20.00

Source: Chakraborty A. et al. (2022). Developing a spatial information system of biomass potential from crop residues over India: A decision support for planning and establishment of biofuel/biomass power plant, Renewable and Sustainable Energy Reviews, Volume 165 ISSN 1364-0321

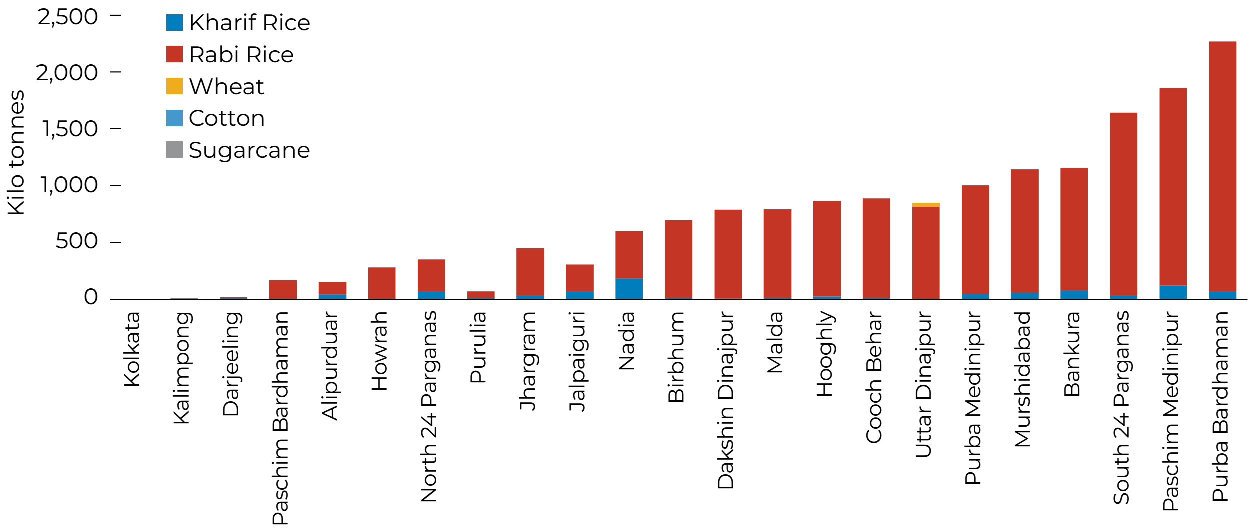
4.2. Potential Reassessment

With the help of the Bhuvan-Jaivoorja portal, the gross and surplus biomass generation in West Bengal was assessed to be 16,351 kilo tonnes (KT) and 869.2 KT respectively. Rabi rice constitutes 95% of the total gross and surplus biomass generation in the state, while the kharif rice constitutes another 5%. Marginal amounts of wheat-based biomass is being generated in only in one district of Uttar Dinajpur.

Overall, Purba Bardhaman district leads in gross and surplus biomass generation at 14% and 13% of the total generation respectively; followed by Paschim Medinipur district at 11.4% share and South 24 Parganas district with 10% share in gross biomass.

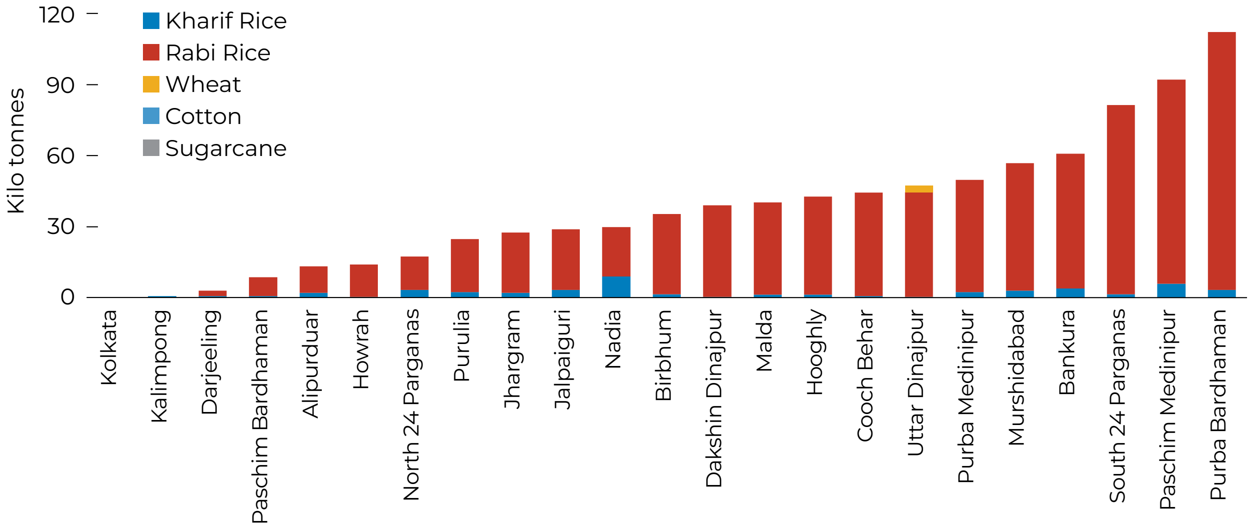
Based on the conversion methodology given above, this total surplus generation in West Bengal can potentially support about 2,863 MW of biomass capacity. Three districts of Paschim Medinipur, South 24 Parganas and Purba Bardhaman account for nearly half of the assessed potential, with 18%, 17% and 13% share respectively. Other high-potential districts include Bankura, Murshidabad and Purba Medinipur with 9%, 6% and 5%, respectively. *(Refer to annexure A2 for the detailed district-wise biomass potential).*

Figure 4.2: District-wise and crop-wise yearly gross biomass generation



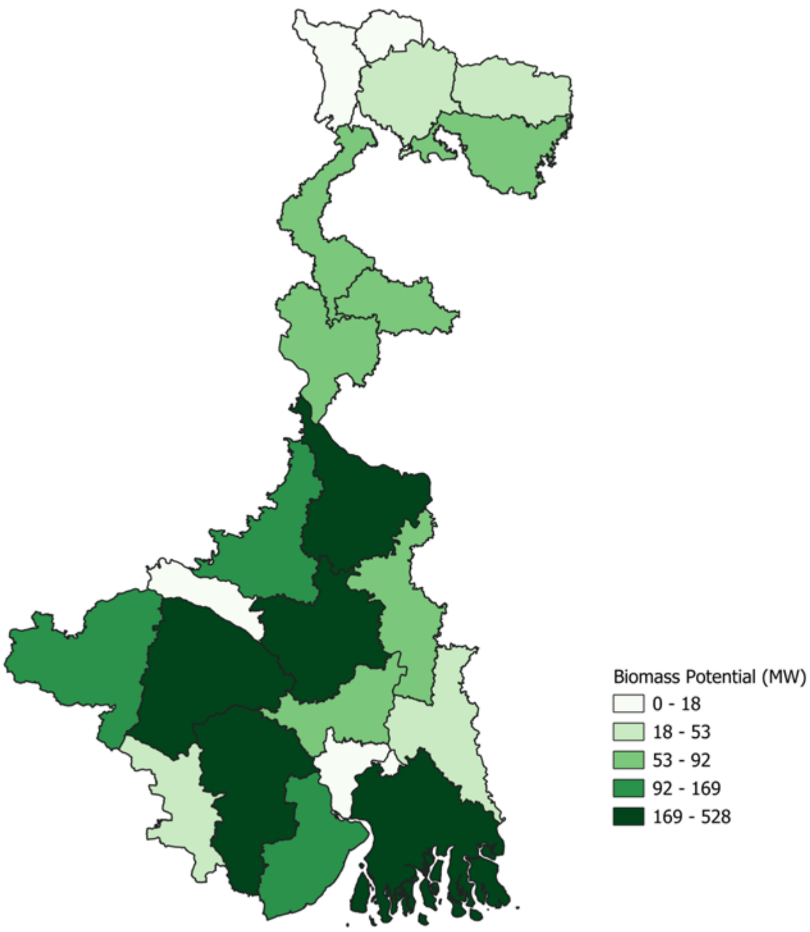
Source: iFOREST assessment

Figure 4.3: District-wise and crop-wise yearly surplus biomass generation



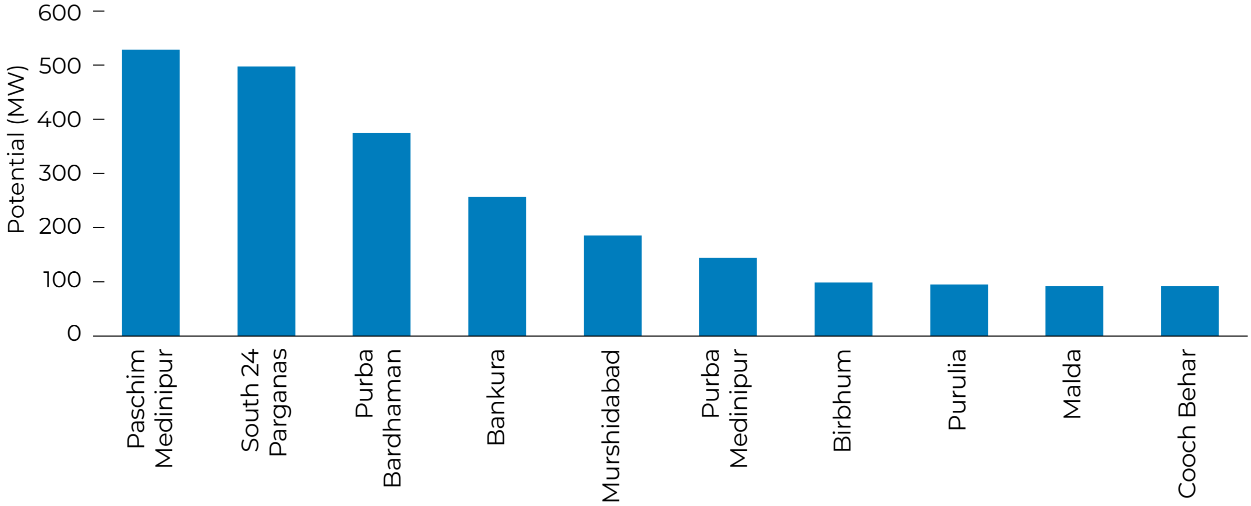
Source: iFOREST assessment

Map 4.1: Spread of biomass potential across state



Source: iFOREST estimated

Figure 4.4: Top ten districts with biomass potential in West Bengal



Source: iFOREST estimates

4.3. Conclusion

West Bengal's biomass potential was reassessed using updated data on district-wise crop residue surplus from the ISRO's JAIVOORJA portal, revealing a cumulative potential of 2,864 MW, which is nearly double the MNRE's assessed potential, and more than eight times the current installed capacity. Given the expanding demand for biopower, not just for power generation but also for biofuel production, there is a need to reassess and reconsider the state's biomass potential. The segment also has important externalities from the perspective of rural livelihood generation and local air pollution control. Going forward, considering the seasonality and spatial distribution, detailed site-specific techno-economic analysis would be required to convert the assessed theoretical potential into actual generation.

Annexures

A1: Waterbody-wise floating solar potential in West Bengal

Sr. No	Name of Dam	Latitude	Longitude	District	Year of Completion	Height above Lowest Foundation Level (m)	Reservoir Area sq. m	PV Potential Low scenario (MWp)	PV Potential Mid scenario (MWp)	PV Potential High scenario (MWp)
1	Kangsabati kumari	22° 57 ‘ 49.90269”	86° 47 ‘ 20.14555”	Bankura	1965	41	3,62,50,000	358.31	895.77	1,791.54
2	Hinglow	23° 49 ‘ 19.59128”	87° 11 ‘ 36.11896”	Birbhum	1976	12	64,80,000	64.05	160.13	320.25
3	Nachan	23° 37 ‘ 2.14106”	87° 19 ‘ 17.41862”	Paschim Barddhaman	1977	14	1,74,000	1.72	4.3	8.6
4	Bara Mandira	23° 49 ‘ 58.35128”	86° 57 ‘ 15.88275”	Paschim Barddhaman	1977	17	2,43,000	2.4	6	12.01
5	Maliarajore	23° 26 ‘ 58.05”	87° 11 ‘ 59.1006”	Bankura	1978	16	19,84,000	19.61	49.03	98.05
6	Parga	23° 26 ‘ 15.56”	86° 4 ‘ 55.30582”	Puruliya	1979	16	5,26,000	5.2	13	26
7	Rupai	23° 18 ‘ 36.02”	85° 55 ‘ 16.79284”	Puruliya	1982	12	7,61,000	7.52	18.8	37.61
8	Dangra	23° 27 ‘ 10.48”	86° 46 ‘ 59.62357”	Puruliya	1982	10	6,65,000	6.57	16.43	32.87
9	Saharajore	23° 18 ‘ 58.47”	86° 3 ‘ 15.32049”	Puruliya	1982	19	17,20,000	17	42.5	85.01
10	Golamarjore	23° 25 ‘ 38.79”	86° 21 ‘ 54.2377”	Puruliya	1989	13	9,51,000	9.4	23.5	47
11	Kumari	23° 9 ‘ 23.32”	86° 17 ‘ 4.60087”	Puruliya	1984	15	17,83,000	17.62	44.06	88.12
12	Lipania	23° 28 ‘ 1.03”	86° 27 ‘ 36.4055”	Puruliya	1985	15	9,31,000	9.2	23.01	46.01
13	Sali	23° 24 ‘ 19.56”	87° 5 ‘ 7.40454”	Bankura	1985	12	19,51,000	19.28	48.21	96.42
14	Tatko	22° 55 ‘ 44.41”	86° 30 ‘ 45.90936”	Puruliya	1985	15	20,28,000	20.05	50.11	100.23
15	Taragonia	23° 28 ‘ 40.83”	86° 23 ‘ 15.32495”	Puruliya	1987	12	6,88,000	6.8	17	34
16	Karrior	23° 25 ‘ 30.44”	85° 56 ‘ 44.47122”	Puruliya	1988	11.5	1,98,000	1.96	4.89	9.79
17	Dimu	23° 25 ‘ 29.65”	85° 58 ‘ 48.87856”	Puruliya	1989	12	3,40,000	3.36	8.4	16.8
18	Khairabera	23° 15 ‘ 49.45”	86° 0 ‘ 19.03005”	Puruliya	1989	21	3,73,000	3.69	9.22	18.43
19	Moutorejore	23° 34 ‘ 48.63”	86° 35 ‘ 13.28494”	Puruliya	1990	14	7,09,000	7.01	17.52	35.04
20	Beko	23° 28 ‘ 40.22”	86° 37 ‘ 42.98162”	Puruliya	1990	16	14,17,000	14.01	35.02	70.03

Annexure A1 continued

Sr. No	Name of Dam	Latitude	Longitude	District	Year of Comple-tion	Height above Lowest Founda-tion Level (m)	Reservoir Area sq. m	PV Potential Low scenario (MWp)	PV Potential Mid scenario (MWp)	PV Potential High scenario (MWp)
21	Turga	23° 11 ‘ 52.41”	86° 3 ‘ 45.49906”	Puruliya	1990	21	3,16,000	3.12	7.81	15.62
22	Barabhum	23° 1 ‘ 55.31”	86° 18 ‘ 31.53632”	Puruliya	1991	11	1,84,000	1.82	4.55	9.09
23	Ramchan-drapur	23° 35 ‘ 15.42”	86° 50 ‘ 15.64343”	Puruliya	1991	15	17,00,000	16.8	42.01	84.02
24	Bandhu extension	23° 16 ‘ 50.36”	86° 8 ‘ 24.25539”	Puruliya	2004	16	47,54,000	46.99	117.48	234.95
25	Futiary	23° 23 ‘ 4.41”	86° 34 ‘ 2.21974”	Puruliya	2004	13.7	7,93,000	7.84	19.6	39.19
26	Hanumata	23° 6 ‘ 38.04”	86° 15 ‘ 51.53985”	Puruliya	2004	19	21,26,000	21.01	52.54	105.07
27	Patloi	23° 21 ‘ 44.12”	86° 29 ‘ 1.85343”	Puruliya	2012	14	18,20,000	17.99	44.97	89.95
28	Teesta Low Dam-iii barrage	27° 0 ‘ 8”	88° 26 ‘ 36”	Jalpaiguri	2013	32	15,64,900	4.64	7.73	15.47
29	Teesta Low Dam-iv	26° 55 ‘ 42”	88° 27 ‘ 21”	Jalpaiguri	2016	45		0	0	0

Source: iFOREST assessment

A2: District-wise biomass potential in West Bengal

	Surplus biomass over fetch area (Kilo tons)						Bioenergy potential over fetch area (Giga Joule/sq. km)						
	Kharif Rice	Rabi Rice	Wheat	Cotton	Sugarcane	total	Kharif Rice	Rabi Rice	Wheat	Cotton	Sugarcane	Total (GJ/ sq.km)	Potential (MW)
Alipurduar	1.97	11.26	0	0	0	**13.23**	30.5	174.56	0	0	0	**205.06**	27.5
Bankura	3.92	56.91	0	0	0	**60.83**	60.7	882.03	0	0	0	**942.74**	257.16
Birbhum	1.35	33.98	0	0	0	**35.33**	20.89	526.67	0	0	0	**547.55**	98.64
Cooch Behar	0.6	43.71	0	0	0	**44.31**	9.22	677.45	0	0	0	**686.68**	92.19
Dakshin Dinajpur	0.31	38.65	0	0	0	**38.96**	4.87	599.1	0	0	0	**603.97**	53.12
Darjeeling	0.58	2.35	0	0	0	**2.93**	9	36.5	0	0	0	**45.5**	3.77
Hooghly	1.24	41.51	0	0	0	**42.75**	19.3	643.4	0	0	0	**662.7**	82.72
Howrah	0.38	13.55	0	0	0	**13.93**	5.84	209.99	0	0	0	**215.83**	12.55
Jalpaiguri	3.24	25.57	0	0	0	**28.81**	50.17	396.26	0	0	0	**446.43**	50.33
Jhargram	1.93	25.57	0	0	0	**27.5**	29.84	396.31	0	0	0	**426.15**	51.31
Kalimpong	0.55	0	0	0	0	**0.55**	8.48	0.02	0	0	0	**8.5**	0.35
Kolkata	0	0.1	0	0	0	**0.1**	0.01	1.49	0	0	0	**1.5**	0.01
Malda	1.24	38.99	0	0	0	**40.23**	19.25	604.36	0	0	0	**623.61**	92.27

Annexure A2 continued

	Surplus biomass over fetch area (Kilo tons)						Bioenergy potential over fetch area (Giga Joule/sq. km)						
	Kharif Rice	**Rabi Rice**	**Wheat**	**Cotton**	**Sugarcane**	**total**	**Kharif Rice**	**Rabi Rice**	**Wheat**	**Cotton**	**Sugarcane**	**Total (GJ/ sq.km)**	**Potential (MW)**
Murshidabad	2.95	53.79	0	0	0	**56.74**	45.68	833.79	0	0	0	**879.47**	185.59
Nadia	8.93	20.78	0	0	0	**29.71**	138.44	322.16	0	0	0	**460.59**	71.69
North 24 Parganas	3.29	13.99	0	0	0	**17.28**	50.98	216.82	0	0	0	**267.81**	43.46
Paschim Bardhaman	0.68	7.92	0	0	0	**8.6**	10.61	122.69	0	0	0	**133.3**	8.47
Paschim Medinipur	5.9	86.18	0	0	0	**92.08**	91.52	1335.82	0	0	0	**1,427.34**	528.7
Purba Bardhaman	3.24	109.01	0	0	0	**112.25**	50.19	1689.67	0	0	0	**1,739.87**	374.66
Purba Medinipur	2.37	47.32	0	0	0	**49.69**	36.77	733.44	0	0	0	**770.21**	144.59
Purulia	2.3	22.41	0	0	0	**24.71**	35.69	347.34	0	0	0	**383.04**	95.03
South 24 Parganas	1.45	79.83	0	0	0	**81.28**	22.48	1237.3	0	0	0	**1,259.77**	497.34
Uttar Dinajpur	0.38	44.06	2.91	0	0	**47.35**	5.96	682.96	50.55	0	0	**739.46**	92.03
Total	**48.8**	**817.4**	**2.9**	**0**	**0**	869.2	**756.4**	**12670.1**	**50.6**	**0**	**0**	**13,477.10**	**2,863.50**

Source: iFOREST Assessment

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Notes

Notes

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