Partnership to Advance Clean Enegy - Deployment
Technical Assistance Program

NTPC SOLAR WIND HYBRID AT KUDGI

WHITE PAPER ON DESIGN APPROACH FOR WIND-SOLAR HYBRIDS

2017

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PARTNERSHIP TO ADVANCE CLEAN ENERGY DEPLOYMENT (PACE-D)

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TABLE OF CONTENTS

FIGURES AND TABLES

ACRONYMS

AEP	Annual Energy Prediction
CEA	Central Electricity Authority
CUF	Capacity Utilization Factor
DPR	Detailed Project Report
EE	Energy Efficiency
EIA	Environmental Impact Assessment
EVI	Emergent Ventures India
GOI	Government of India
kV	Kilovolt
KERC	Karnataka Electricity Regulatory Commission
KREDL	Karnataka Renewable Energy Development Limited
MNRE	Ministry of New and Renewable Energy
MOP	Ministry of Power
MW	Megawatt
NIWE	National Institute of Wind Energy
NTPC	National Thermal Power Corporation
OEM	Original Equipment Manufacturer
PACE-D	Partnership to Advance Clean Energy Deployment
PE	Plant Evacuation
PFR	Person for Reporting/Responding
PLF	Plant Load Factor
PPA	Power Purchase Agreement
PSU	Public Sector Undertaking

PV	Photovoltaic
RE	Renewable Energy
SLD	Single Line Diagram
SNA	State Nodal Agency
TPS	Thermal Power Station
US AID	United States Agency for International Development
WTG	Wind Turbine Generators

EXECUTIVE SUMMARY

1.1 BACKGROUND

This document has been prepared for United States Agency for International Development (USAID) under Partnership to Advance Clean Energy Deployment (PACE-D) Technical Assistance (TA) program. This document explains the basic design approach to be adopted for deployment of wind-solar hybrid power projects in India. It covers all the aspects involved in this particular process, including design methodology, identification and evaluation of prospective sites for such hybrid projects, optimization of wind turbine and solar module placement, total capacity mix optimization for hybrid plants, and finally power evacuation optimization. It also gives a brief analysis of the savings from such hybrid plants and the Environmental, Social and Governance (ESG) norms that shall be considered while implementing these projects.

1.2 PROBLEM STATEMENT

India has a large estimated potential of wind and solar energy, wherein a majority of states display good solar energy potential, and some states exhibit good wind energy potential. Development of both wind and solar technologies require land, which is a limited resource. For example, wind turbines must be placed at large distances from each other, resulting in large amounts of underutilized land between turbines. Also, solar and wind energy reaches peak generation at different time of day and in different season therefore current allocation of power evacuation capacity is being used inefficiently. Hence, it is critical to address such inefficiency and poor utilization of resources.

1.3 PROPOSED SOLUTION

An ideal solution, to ensure optimized utilization of land, evacuation capacity and common infrastructure is identification of sites rich in both solar and wind resource, and the establishment of wind-solar hybrid projects. These projects can lead to significant savings in capital costs and land and can better serve India's renewable energy plans.

To encourage the wind-solar hybrid projects, the Ministry of New and Renewable Energy (MNRE) has released a draft policy on wind-solar hybrids, which sets a target to achieve 10 GW of energy from wind-solar hybrids by 2022.

This paper outlines the design of greenfield wind-solar Hybrids projects.

1.3.1 SETTING UP GOALS FOR WIND-SOLAR HYBRID DESIGN

Wind-Solar hybrids can be designed to serve different optimization goals such as:

1. Maximizing energy generation (kWh/m^2) from land.
2. Minimizing Levelized Cost of Energy (LCOE) INR/kWh
3. Maximizing energy transmitted from a transmission Capacity (MWh/MW)

4. Improving balance/variability of power generation
    a. Reducing peak to average ratio for power generated
    b. Reducing coefficient of variation for power generated
5. Matching generation profile with load profile

The goal 5 is likely to be important from an electricity buyer's perspective that needs to match generation with the load pattern and would require energy storage support, in addition to inherent pattern of wind and solar generation at different times of the day. Energy storage will also make an impact on goal 3, 4 and 5; although at present it adds significant cost to delivered power.

The third goal of maximizing MWh/MW would become critical when considering inter-state transmission of renewable energy (RE) as it would minimize transmission costs. The point of connection charges (PoC) for inter-state transmission system (ISTS) are very high and would result in significant costs for long term access, once the waivers granted for RE expire in 2019.

In the following sections of this report, the study has focused on designs for maximizing energy generation (goal 1) from the land, while minimizing LCOE. These goals have been cited as most important by the investors at present.

Development of large scale wind-solar hybrid projects is still at a nascent stage in India, and further studies are needed for development of technical, commercial as well as policy aspects impacting the design of projects. This paper showcases the approach taken by NTPC in designing of the Kudgi project with the primary goal of maximizing energy generation.

1.3.2 METHODOLOGY FOR DEVELOPMENT OF WIND-SOLAR HYBRIDS

The first step for development of the wind-solar hybrid project is site identification. The site has to be selected based on availability of both solar and wind resource, contiguous land availability, site accessibility, availability of evacuation infrastructure and water for cleaning the solar panels.

While designing, it is recommended to fix wind turbine locations first as

a. The generation from WTG is location sensitive
b. The solar module placement is flexible and can be laid around WTG's
c. It can help selection of an optimum configuration that minimizes shadow losses

A detailed shadow analysis is carried out subsequently for planning the solar module placement. After this the capacity mix and power evacuation capacity is analyzed and optimized on the basis of total generation, cost of delivered energy, generation losses and grid balancing. Finally, environmental, safety and governance norms that may apply to the wind-solar hybrid project are established.

2 INTRODUCTION

India has an estimated renewable energy potential[1] of about 900 Gigawatt (GW) including 102 GW from wind, 750 GW from solar and 25 GW from bioenergy[2]. As part of its commitments under the Paris Agreement, the country aims to develop 175 GW of renewable energy by 2022; is committed to reduce the energy emissions intensity by 30 percent to 35 percent from 2005 levels; and increase share of non-fossil fuel energy to 40 percent of India's energy mix by 2030.

The Government of India (GOI) through the Ministry of New and Renewable Energy (MNRE) has been encouraging the accelerated uptake of renewable energy in order to address challenges around the demand supply gap as well as climate change and energy security. As of December, 2017, India has 18.2% of its share of power from renewable sources, with about 60.158 GW installed renewable capacity[3].

Solar and wind have complementary generation patterns, and simultaneous use of both the resources can enhance utilization of a given land area. In addition, wind turbines are usually placed at large distances from each other in a typical wind farm, resulting in wastage of large tracts of land. Unused land can be better utilized by installing solar panels in the shadow-free area available around wind turbines.

India has large estimated potential of wind and solar energy and a number of regions are rich in both resources. It is therefore likely to undertake development of wind-solar hybrids. In this regard, a draft national wind-solar hybrid policy was released by MNRE in 2016, which targets 10 GW of wind-solar hybrid by 2022[4]. Recent assessments highlight significant potential from hybrid projects; a study carried out by CSTEP in year 2015 (Refer appendix 1) estimated the wind-solar hybrid potential at 10,300 GW across India (This estimated potential is based on GHI > 4.5 kWh/m^2 and Wind speed > 6 m/s at 120m hub height). The estimates take into account areas where both forms of energy show maximum potential, incorporating the wind and solar resource, along with other factors like land use, land cover data, substations, topography, roads, water bodies, etc.

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[1] As of 18th December, 2016, India has 15% of its share of power from renewable sources, with about 46 GW installed renewable capacity.

[2] http://pib.nic.in/newsite/PrintRelease.aspx?relid=155612

[3] http://powermin.nic.in/en/content/power-sector-glance-all-india

[4] http://mnre.gov.in/file-manager/UserFiles/Draft-Wind-solar-Hybrid-Policy.pdf

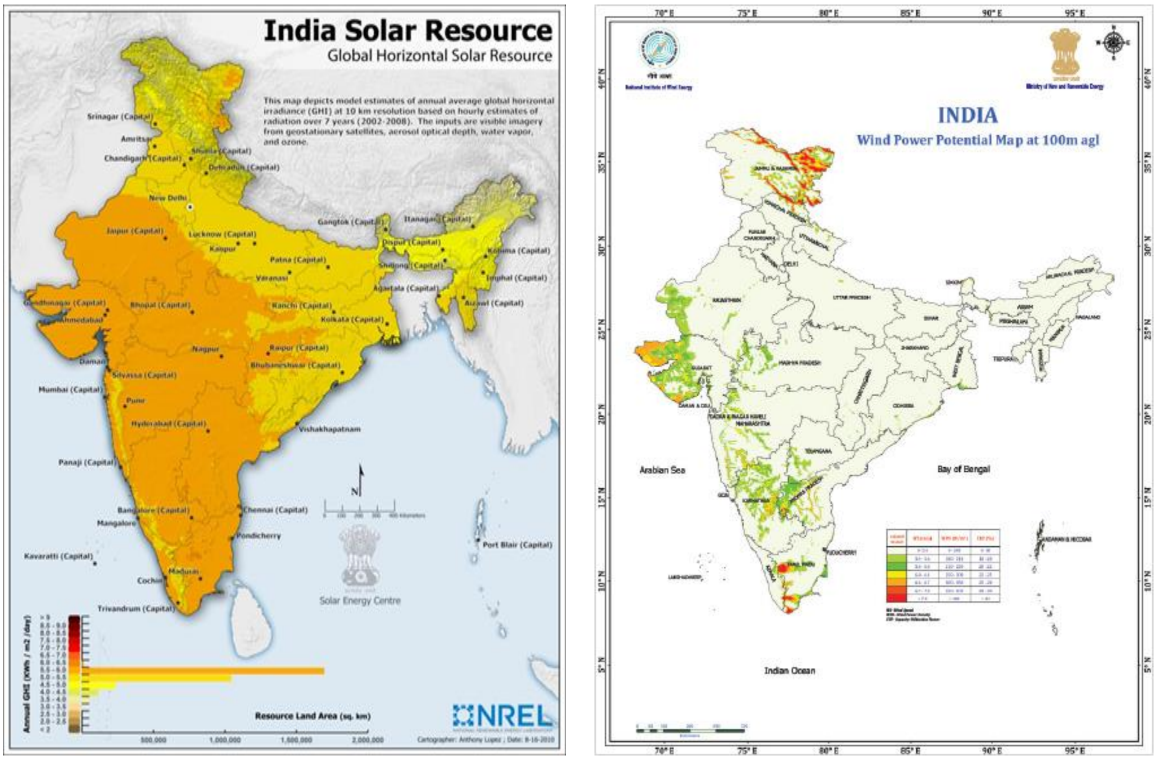

Figure 1: Solar Global Horizontal Irradiance (GHI) map of India (source: MNRE) and Wind power potential map of India (source: NIWE)

2.1 Advantages of Wind-Solar Hybrid

Wind-solar hybrid projects offer several operational synergies, leading to long-term savings in capital investments, operation and transmission of power from hybrid plants. Certain infrastructure could be common for both projects and result in reduced capital costs. The complementary generation patterns lead to more balanced generation curves, with less variability, and ensure a stable and robust injection in grid, with reduced grid integration costs.

Further, projects will be able to adhere to stringent scheduling and forecasting guidelines, and experience reduction in penalties and duties paid for non-adherence to statutory compliances.

Key benefits of wind-solar hybrids are:

a. **Effective utilization of land and renewable energy resources**
Empty land available for solar and wind projects might become a major limitation in the future and land costs and acquisition challenges will also keep increasing. Therefore, land resource should be used effectively to ensure maximum generation. It has been estimated that energy generation per unit area of land, in the case of a large scale wind-solar hybrid zone will be significantly higher compared to an only wind/solar scenario. The Plant Load Factor (PLF) for a

hybrid plant will also be better than solar plant and might reach the PLF for wind plant.

For example, in an assessment for a site in Karnataka, the annual energy generated with only wind[5] is 35.0 kWh/ m^2 /year., if solar is added to the same area then the hybrid energy generated increases to 115.9 kWh/ m^2/year. [6] This output can be further increased to ~150 kWh/ m^2 /year. with denser placement of solar capacity (where only half the area is left empty compared to area required to be left for avoiding shadows completely). The solar generation alone is estimated at 126.8 kWh/ m^2/year. Also, The PLF achieved form the same site for wind is 39.0 percent while for solar it is 18.0 percent, and for solar- wind hybrid, it is 36.3 percent[7].

b. Savings on evacuation system and common infrastructure cost

Wind power can be evacuated using the evacuation infrastructure for solar[8], since time of day generation patterns of wind and solar are usually complementary, with wind power generation picking up after sunset and reaching peak generation late night, thereby effectively utilizing the power evacuation infrastructure and saving costs.

Other infrastructure such as roads, security, plant control, spares warehousing, energy storage, forecasting and scheduling etc. may be created cost effectively and with high quality and reliability, using the most appropriate technical specifications. This will result in savings of capital cost. For example, Table 1 details the savings gained if a hybrid plant is set up instead of a wind project for the same site in Karnataka (assuming 576 MW wind and 2140 MW solar) in a 7.5 km x 7.5 km hybrid zone.

Table 1 Savings on evacuation and common infrastructure

Avenue for Savings	Savings (INR Million)	Rationale
Land	694	Land is more expensive when bought for wind
Land development charges	172	Wind requires less extensive land development than solar, and costs 50% less
Evacuation Infrastructure	2223	Common infrastructure can be shared between wind and solar generation
Lights,	246	Common utilities e.g. warehouses, control

5 For 2 MW G-114 wind turbine at 39% PLF and 3DX5D configuration

6 For modules at 10 degree tilt without trackers and with AC: DC ratio of 1:1.3

7 PLF for Wind-Solar Hybrids is defined w.r.t evacuation capacity.

8 This is true for greenfield sites with much higher solar capacity. For brownfield expansion of wind power projects, using solar, the reverse might be true. Solar would be evacuated using the evacuation infrastructure for wind.

warehouse, control center etc.		centers can be shared
Common permitting	288	Avoided in hybrid, covered by solar
Total Savings	**3624**	**Savings of INR 6.29/W for wind capacity**

In addition to this, about INR 10 million per MW (INR 10/W) would be saved in avoiding additional transmission capacity investments[9].

c. Reduced operating costs due to shared services

Wind and solar have completely independent and complementary generating patterns, so operations and maintenance schedules can be optimized for best utilization of non-operating and lean hours[10] for routine maintenance work without losing out on generation, as would be the case in a pure solar or wind project. Further, once the team appointed at site are familiar with the workings of both wind and solar, a very lean and highly experienced team can carry out electrical and civil maintenance works, effectively saving on manpower and material cost (of keeping two separate teams) on an annual basis.

Services such as administration, security, accounting, forecasting and scheduling can also be shared and result in reduced costs. For example, total operational savings for wind after hybridization for the site in Karnataka are estimated to be around INR 0.025/ kWh, as savings from common O&M team are about INR 0.015/ kWh, and savings from common administration, accounting and security services are about INR 0.01/ kWh.

d. More balanced power mix for sale

Solar generation peaks around noon (11.00 am - 2.00 pm) whereas wind picks up normally in the afternoon. Hence, benefits of balancing and optimal sizing of the transmission infrastructure are realized. Also, wind picks up during late summer and the monsoon season when solar drops because of the clouds or because of high temperatures (summer), which again shows the complementary nature of wind and solar. This ensures a more balanced power mix for sale, with lesser ratio of peak to average power for the same hour throughout the year if wind or solar is taken separately. For example, for the site in Karnataka the peak to average ratio for a hybrid plant decreases to 3.5 from 4.15 for solar plant.

The wind-solar hybrid project benefits from diversification of resources due to spatial distribution of RE generators, different technologies (wind, solar) etc.,

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[9] The report of the committee to review transmission planning, connectivity, long term access, medium term open access and other related matters, Sep 2016. http://www.cercind.gov.in/2016/whatsnew/OA.pdf

[10] For solar this would be nights and early morning and for wind it would be 6-8 months of lean season.

improving predictability of power generation, more balanced generation curves and reduced investments in energy storage when optimizing delivery for load matching, scheduling, transmission cost, and higher ability to meet more stringent norms for grid interconnection (control over power injection, voltage etc.).

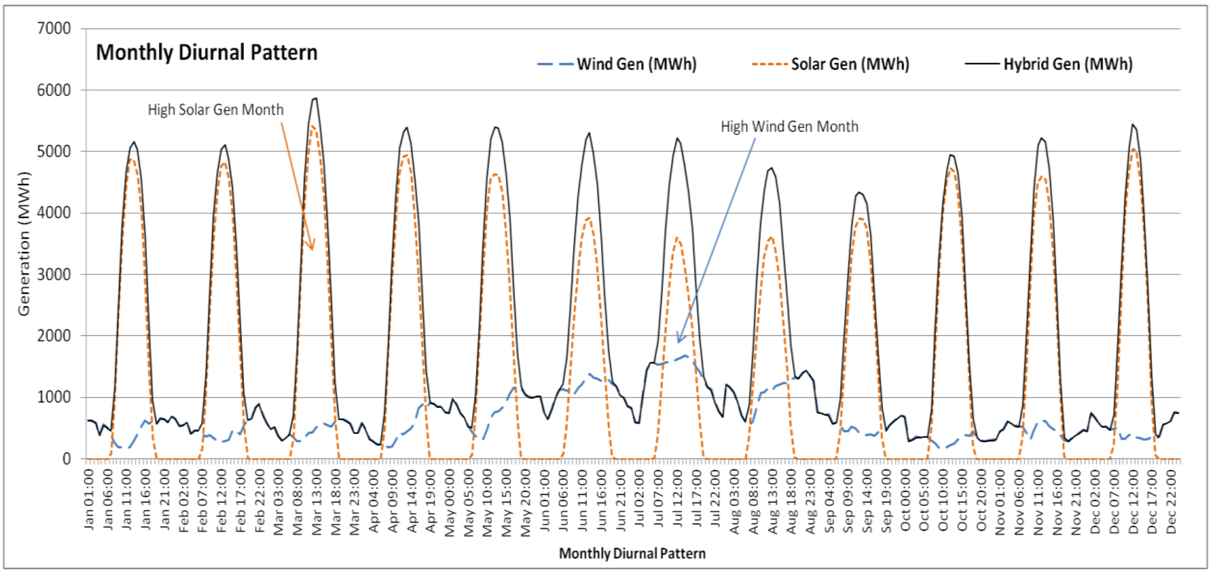


Figure 2: Wind-solar energy generation patterns throughout the year

Figure 2 illustrates the effect of generation smoothening and utilization of common plant evacuation infrastructure at a mixed wind-solar development zone in which a large-scale solar park has been co-located with a large wind farm, utilizing common infrastructure and shared development of the entire zone. One can see balancing occurring between May to Sep generation as solar drops and wind picks up

2.2 Design Approach Of Wind-Solar Hybrid Project

The basic approach for designing any wind-solar hybrid project shall start with the identification of sites with good wind and solar resource. For a wind-solar hybrid, it is important that both the resources should be ideal for maximizing the benefits from the hybrid project. Large part of India has ideal solar GHI, whereas, ideal wind resource is limited to a few states. Hence, wind-solar hybridization requires identification of sites rich in wind resource followed by sites rich in solar resource. The wind-solar hybridization can be carried out in four ways:

1) Greenfield wind-solar hybrid project
2) Brownfield wind-solar hybrid project with wind turbines installed on specified land points and solar placed around these turbines to evacuate from the wind evacuation lines.
3) Brownfield projects with wind turbines already installed in contiguous land parcels and solar modules have to be installed between them.

4) Brownfield projects with solar modules already installed and wind turbines installed on land areas where no solar has been set up due to unevenness and other land contour issues.

For all the above ways of hybridization, the methodology of designing a wind-solar hybrid remains the same, with some minor differences from one type to the next. However in cases 2, 3, 4, careful consideration will need to be given to up gradation of evacuation capacity, regulatory approvals for power sale and evacuation of extra generation etc.

For all types of projects, after identifying the sites, with due consideration to the ESG norms and guidelines, the solar module placement shall be done in such a way as to minimize energy loss due to shadows and hot spotting. Final capacity mix and power evacuation shall be optimized to realize minimum LCOE and transmission costs. The approach which can be chosen for designing the wind-solar hybrid project is depicted in Table 2.

Table 2 Design approach flow chart for wind-solar hybrid project

1
- **Site identification for solar-wind hybrid projects**

2
- **Wind Turbine Placement and Energy Yield Optimization**

3
- **Solar Module Placement and Energy Yield Optimization**

4
- **Optimize the final capacity mix**

5
- **Design common services and facilities**

6
- **Establish compliance of ESG norms relevant to these projects**

3 Site Identification for Wind-solar Hybrid Projects

The main objective for setting up any wind-solar hybrid project should be to maximize benefits from given land and energy resources. These benefits shall be quantified in terms of maximizing energy generation and cost savings. So, site identification for wind-solar hybrid plants become very important, and site selection can be based on the following (two or more) criteria:

1. Energy generation from the area, i.e. kWh/m^2
2. Delivered energy costs at the evacuation substation (INR/kWh) or to proposed load centers (INR/kWh) – this will include cost of generation, including allocated costs of common infrastructure and cost of transmission till delivery point. It will be estimated for each technology and then weighted average will be calculated for the hybrid project.
3. Risks (Ease) of Development, there may be factors which may make hybrid projects in some areas relatively easy to implement and in some area more difficult. These factors may relate to quality of existing infrastructure, ESG factors, complexity of geographical terrain, climatic factors, location (urban, rural, industrial, defense etc.) around the project etc.
4. Economic impact on local community - possibly a factor such as 'total economic value gain by local community/ kWh of power generated' may be used.

After identifying sites with ideal wind resource that can also optimize solar resources, sites with suitable land use land cover, infrastructure, and connectivity can be identified. Different GIS layers can be created, and data filtering used to superimpose GIS layers on top of each other, while optimizing various other parameters towards site selection for the wind-solar hybrid park development.

First Category of Layers: "Integrated RE Resource Data Assessment" combining resource data with information on land use, population and natural disaster zones

Second Category of Layers: Infrastructure data related to parameters like transmission and evacuation, road access, water linkage, soil data, groundwater availability and telecommunication is important to plan any project, and assess the feasibility of a project

Third Category of Layers: Layers for ESG related data like land ownership, development plans, ecologically or socially sensitive areas shall be considered for developing wind and solar projects, so as to comply with all the environment or social norms or guidelines of the particular state or country

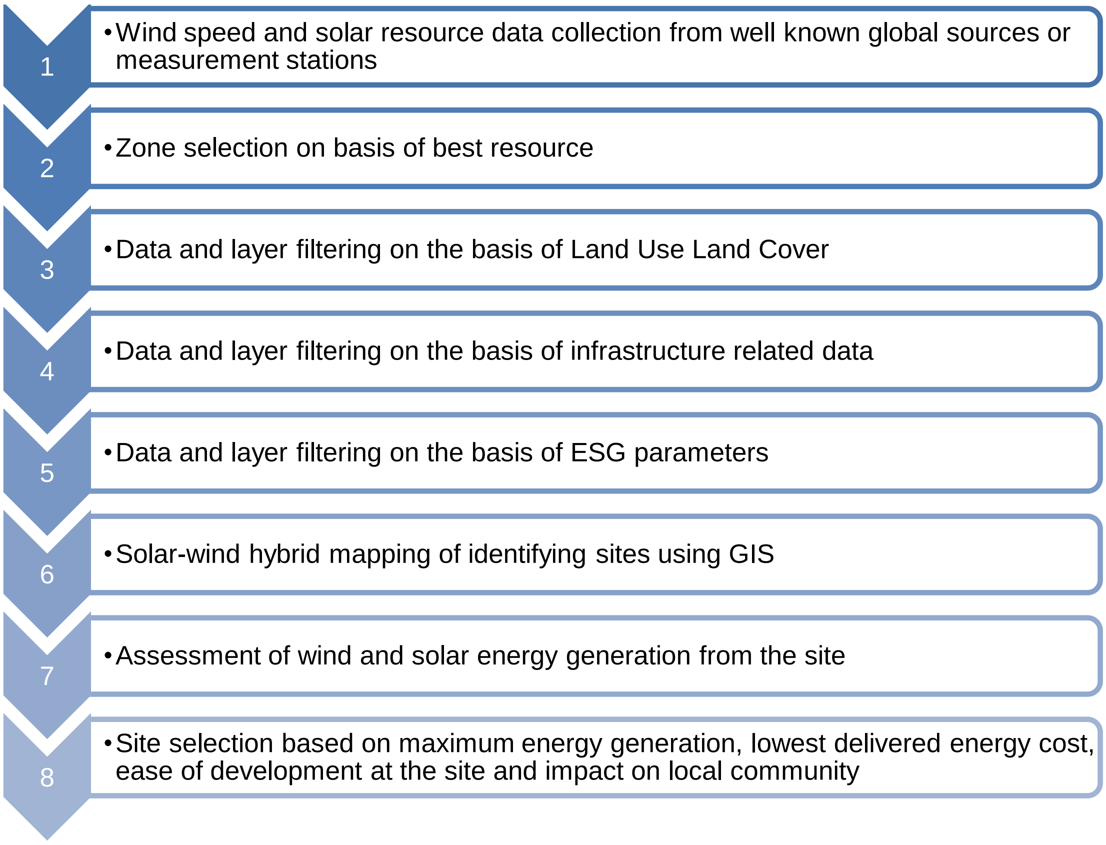


Figure 3: Methodology for site identification

3.1 Resource Availability and Resource data

On a wind-solar hybrid project with access to both wind and solar resources, wind resource estimation shall be carried out first and solar resource estimation shall be done only after the selection of sites with good wind resource. The GIS layers for wind resource data and solar resource data shall be super imposed and the best possible generation combination will be chosen:

- **Wind resource layer:** Mapping to be done to identify sites with good wind resource in terms of wind speed and higher PLF. Site terrain should be suitable for installation of wind turbines.
    - Wind speed map
    - Digital Elevation Model (DEM)
    - Wind power density map
    - Average slope
    - Contour map
- **Solar resource layer:** Out of the selected wind resource rich sites, sites with good solar radiation to be mapped
- **Total RE resource layer:** The selected sites should be rich in both, solar and wind resource, in order to achieve optimum generation and PLF values

The wind resource data collection shall begin with the modeling of wind resource followed by the assessments carried out by the concerned utilities or state nodal agencies in the past. This shall be checked for data consistency, forecast errors and equanimity of assumptions used in the model, and then further validated with data from existing C-WET wind masts data.

Potential areas with high wind energy capacity shall be identified, considering the existing infrastructure and power evacuation, and a meso map of wind speed over the entire region shall be developed using all databases. A ranking method for wind speeds can be developed as demonstrated in Table 3.

Table 3: Sample wind speed ranking

Class Name	Wind Speed (m/s)
I	>8.5
II	7.5 – 8.5
III	6.5 – 7.5
IV	5.5 – 6.5
V	<5.5

The annual energy output from predominant Wind Turbine Generators (WTGs) shall be computed for the identified hybrid zone at 80 m height. For Solar Resource Assessment, NREL, SolarGIS or other well accepted sources can be used for initial data analysis. The available assessments carried out earlier by utility/nodal agencies can be checked and the assumptions should be validated. The data shall be ground-vetted using data from C-WET solar measurement stations (currently there are 121 solar measurement stations of C-WET[11]). Data from these stations can be procured by the assistance of nodal agency/ MNRE.

3.2 LAND AVAILABILITY

The availability of optimum land is another major aspect of site selection. The uniformity of terrain, right of way and land ownership shall be taken into account. Also, the site shall be selected by considering the roughness index for wind power plant (WPP). In a hybrid project, the shadowed area due to planned wind turbines shall be taken into account for a greenfield wind-solar hybrid project.

Availability of groundwater or other water sources, soil data, occurrence of natural disasters shall be considered while assessing the available land. Apart from this, the available land should not be in an ecologically or socially sensitive zone, as it may hinder project development. The following parameters shall be considered for land availability assessment:

[11] http://niwe.res.in/department_srra_stations.php

- **Land use, Land cover (LULC) layer:** After selection of sites rich in solar and wind resource, mapping of LULC should be carried out and unsuitable sites filtered out. These unsuitable sites can include:
    - Waterways (surface water bodies)
    - Built-up areas
    - Forest and forest reserves
    - National Parks
    - Roads (national and state highways)
    - Airport/Port/Railway (main)
    - Border areas (with 10 km buffer)
    - Heritage/Monuments

- **Natural disaster zones and their types:** Sites prone to frequent natural hazards can be filtered out to prevent losses to life and property based on the following criteria:
    - Seismic sites – prone to earthquakes and
    - Cyclonic cites which are prone to cyclonic weather conditions

3.3 SITE ACCESS AND CONNECTIVITY

It is imperative to have appropriate connectivity infrastructure, including roads, railways, or waterways in place to reach the site. Access roads are required for the transportation of wind and solar components, approach of planning, installation and inspection team, workers and carrying construction material. Similarly, communication accessibility and ease of installing the project shall be considered while selecting the site. All the parameters related to access and connectivity shall be verified during site visits. This infrastructure remains largely the same for large wind and solar farms. However, in the case of wind farms, access requirements may differ a little due to the large size of the towers and blades that need to be brought in.

3.4 POWER EVACUATION

The power take-off facility and infrastructure is a basic requirement to select the site for project installation. The location of sub-station and distance from site plays a vital role as development of transmission infrastructure can substantially add to project cost. The capacity of nearest power take-off point (sub-station) predominantly decides the installation capacity of a wind-solar hybrid power plant.

The major factor which influences the site identification for a wind-solar hybrid is that both solar and wind resource availability should be ideal and complimentary at site to realize maximum benefit from the site.

4 WIND TURBINE AND SOLAR MODULE PLACEMENT

The placement of WTGs is based on WTG Micro-siting; it is the optmization of energy production through appropriate placement of wind turbines after considering all the geographical and physical constraints. The wind turbines in a wind farm area are placed to achieve maximum energy production.

The solar PV plant shall be laid out after identification and consideration of shadows cast by the WTGs. The flow chart in Table 4 shows the steps involved in placement of solar modules and energy estimation.

Table 4 Process flow chart for solar module placement

- Micro-siting of WTGs
- Identification of shadow free zones
- Obtain solar data GHI from well-known sources
- Check data for authenticity
- Develop scenarios for solar PV optimization based on AC:DC ratio, tilt angle, pitch
- Carry out generation simulations
- Extrapolate the AEP from simulations to arrive at net AEP figures from the entire project capacity

Refer Appendix 2 for further details on wind micro-siting and module placement.

4.1 SHADOW ANALYSIS

After wind resource assessment and optimizing wind turbine placement, shadow analysis should be done for optimizing the placement of solar modules. This analysis would take into account any shadows cast by wind turbines or other attributes which may result in faults and module damage due to hot spotting. Shadow analysis should be carried out for a day and annual movement of the sun.

Shadow formation due to moving turbine blades

Hot-spot heating occurs when there is one low current solar cell in a string of at least several high short-circuit current solar cells. It occurs when electrons accumulate in cell and heat surge is experienced as the cell starts to act like a resistor. It results in lower power output and accelerated degradation of materials in the area.

This happens when sharp and persistent shadows affect a few cells. Wide shadows, moving shadows and shadows in low light conditions (evenings or mornings) are likely to result in very little/no hot-spotting.

In a wind-solar hybrid park, wind turbines will cast shadows on the solar panels, leading to loss in energy generation. It should be taken into account while placing the solar modules and they should be placed in a manner that no shadow falls on them between 10.00am and 4.00 pm.

In addition to turbine tower shadow, shadow flicker occurs due to rotation of wind turbine blades and cause shadows to flick on and off. The effect lasts for a very short span of time, and happens only when the sun is shining and is at a low angle. These shadow flickers may cause frequent alternation in light intensity and affect the PV power output. Recent advancements in inverter technology with provisions of dynamic maximum power point tracking (MPPT) make it possible to track and quickly adjust the voltage levels for maximum power for the current.

4.2 LAYOUT DESIGN

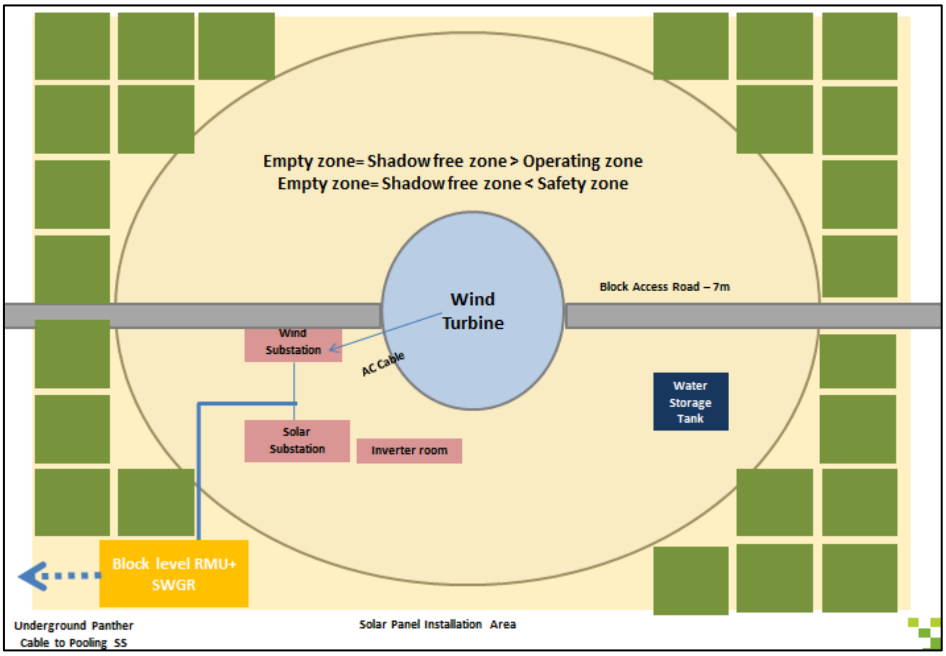


Figure 4 Shadow free area

The empty space left around a WTG can be between following limits

- **Safety Zone** = Wind turbine safety area = Hub Height + ½ Rotor Diameter + 5 meters[12]

The safety zone is defined for keeping safe distance from public roads, railway tracks, highways, buildings, public institutions, living habitats and EHV lines. In project development on contiguous lands where public is not allowed, this can be ignored.

- **Operating zone** of a WTG is the minimum empty space around a WTG required for maint**enance work. T**his area is required to allow bringing down blade assembly for maintenance and keeping it on ground without any interference[13]

In the study, it was found that empty zone required to achieve very low shadow loss would be **less than the safety zone** and **greater than the operating zone**. It was found that this empty zone will avoid shadows during maximum generation time

[12] Safety zone would be about 172 meters for 2 MW Gamesa G-114 WTG with hub height of 106 meters and rotor diameter of 114 meters

[13] Operating zone is normally blade diameter x 1.1 to keep an area free where wind rotor can be taken down.

periods (10 am – 4 pm) and encounter minimal shadows early in the morning (before 10 am) and late afternoon (after 4 pm, in most western or southern states of India), during which generation from solar is low, and therefore, likelihood of hot spots will also be low.

Analysis was carried out for reducing areas of empty zone. We observed a miniscule increase in near shadow losses, till Operating Zone limit was reached, while the increase in the capacity of the solar PV plant was significant.

Appendix 3 shows an example with calculations and analysis for solar modules in the safety and operating zones for the same site, with two different radii to optimize solar capacity.

To optimize solar capacity installation, different scenarios based on AC:DC ratio, pitch, tracker and tilt angle are developed, the following sections discuss about these scenarios and then traded-off among the dependent variables such as annual energy production, CUF, PR and generation per square meter to select one scenario.

4.2.1 DC: AC RATIO

The DC:AC ratio is the ratio of installed DC capacity of the solar power plant to the AC output from inverter. Connecting higher DC capacity (MWp) to inverters (MW_{AC}) facilitates the higher power generation.

Traditionally the PV system designers have used the ratios anywhere between 1:1.1 and 1:1.25, in recent times the designers are opting for higher AC:DC ratios i.e. up to 1:1.35.

This selection of ratio primarily depends on

a. The inverter warranties – In current scenarios, a manufacturer is comfortable in providing extended warranties up to ratio of 1:1.35.
b. Location of the site – Solar plants don't reach peak DC generation as the site temperature and radiation conditions are different from standard test conditions (STC). The AC:DC ratio can be increased, till permitted inverter limits are reached in site conditions.
c. Trade off between the reduced capex/ unit of power generation and loss of power generated when generation is higher than inverter capacity.

An analysis has been carried out for a site in Kudgi, Karnataka where it has been found that when all other variables are kept constant, the annual energy generation increases linearly with increase in DC overloading.

Table 5 Comparative study for different AC: DC ratio

Case	Configuration	AC:DC ratio	Angle (Degree)	Pitch (m)	Tracker	Installed Capacity - kWp	Installed Capacity - kWac	Generation (MWh / Year)

1	PV Table as Shed	**1:1.3**	10	7.5	Fixed	7808	6000	**12,812**
2	PV Table as Shed	**1:1.35**	10	7.5	Fixed	8102	6000	**13,286**

4.2.2 PITCH/INCLINATION ANGLE

The pitch represents the distance between rows of modules (the pitch) required to avoid significant inter-row shading. In the analysis for the same site in Karnataka, it has been found that the yield loss has been saved by increasing the pitch.

Table 6 Comparative study for different pitch (m)

Case	AC:DC ratio	Angle (Degree)	Pitch (m)	Tracker	Installed Capacity - kWp	Installed Capacity - kWac	Generation (MWh / Year)
1	1:1.3	10	**5**	Fixed	6016	4680	**9,748**
2	1:1.3	10	**7.5**	Fixed	7808	6000	**12,812**

4.2.3 TRACKER USE

Sun trackers (single/double axis) are used to increase the annual average irradiation and broadly, they are capable of increasing the annual energy yield by up to 20% by using single-axis and 30% by using dual axis trackers. [14]

The following table provides the comparative study of single axis tracker (SAT) and dual axis tracker w.r.t. fixed tilt configuration.

Table 7 Comparative study of single axis tracker and dual axis tracker

Parameters	Single axis tracker	Dual axis tracker
Generation	Increases by 17%	Increases by 25%
Land Requirement	30%-50% increase in area/MW (5-7 Acres/MW)	(80%-100% increase in area (7 to 9 Acres/MW))
Structural Cost	Increases by 40-50%	Increases by 50-60%
Land leveling	Highly sensitive to land undulation	Not sensitive

[14] Actual field performance shows energy yield improvements of ~17% for single axis tracker and ~ 25% for double axis trackers.

The optimization of solar PV module placement and annual energy generation can be carried out on the basis of scenario analysis. Chart in Table 8 represents the different scenarios developed for the site in Karnataka, based on different tilt angles, pitch, with and without tracker and AC:DC ratio. The scenarios with the maximum generation and most favorable cost should be considered for the hybrid plant to ensure maximum utilization of land and resources. Also, balanced generation from wind and solar should be taken into account to decide the optimum capacity mix for the wind-solar hybrid plant.

Table 8: Scenario analysis - Solar module placement

S.No	PV Table	AC:DC ratio	Tilt Angle	Pitch (m)	Tracker	Capacity – kWp	Capacity - kWac	Gen (MWh / Year)	P.R (%)	C.U.F (%)	Area Required (kWp/m^2)	Gen per unit area (kWh/m^2)
1	2 Portrait	1:1	20	6	Fixed	6016	6000	9,849	78.37	18.69	0.09	148.66
2	2 Portrait	1:1.2	15	5.5	Fixed	6016	5000	9,873	78.87	18.73	0.10	159.01
3	2 Portrait	1:1.3	10	5	Fixed	6016	4680	9,748	78.63	18.50	0.11	180.12
4	3 Portrait	1:1.3	10	7.5	Fixed	7808	6000	12,812	79.63	18.73	0.10	162.65
5	3 Portrait	1:1.35	10	7.5	Fixed	8102	6000	13,286	79.58	18.72	0.10	162.72
6	2 Portrait	1:1.2	+/- 5 E-W	5	SAT without BT	6016	5000	10,125	80.81	19.21	0.11	187.09
7	2 Portrait	1:1.2	+/- 8 E-W	5.5	SAT without BT	6016	5000	10,265	79.84	19.48	0.10	165.33
8	2 Portrait	1:1.2	+/- 50 E-W	5.4	SAT without BT	6016	5000	10,571	78.84	20.06	0.10	174.57
9	2 Portrait	1:1.2	+/- 50 E-W	5.5	SAT without BT	6016	5000	10,620	78.78	20.15	0.10	171.04
10	2 Portrait	1:1	+/- 50 E-W	6	SAT without BT	6016	5000	10,836	78.61	20.56	0.09	163.55
11	2 Portrait	1:1.2	+/- 50 E-W	6.5	SAT without BT	6016	5000	11,022	78.65	20.91	0.08	153.93
12	2 Portrait	1:1.2	+/- 50 E-W	7	SAT without BT	6016	5000	11,178	78.68	21.21	0.08	145.76
13	2 Portrait	1:1.2	+/- 50 E-W	7.5	SAT without BT	6016	5000	11,300	78.71	21.44	0.07	138.19
14	2 Portrait	1:1.2	+/- 50 E-W	8	SAT without BT	6016	5000	11,406	78.77	21.64	0.07	131.33

(Where SAT is Single Axis Tracking and BT is Back Tracking)

In the table 8 above, Scenario 5 with 3 portrait PV module table, 1:1.35 AC:DC ratio, 10 degrees tilt angle and 7.5 meters pitch had the maximum energy generation of 13,286 MWh per year.

It is ideal to carry out wind micro-siting first. Solar PV modules shall only be placed in the shadow free area of wind turbines after shadow analysis. For uneven lands, where WTG placement is done in a contiguous manner at a very large distance from one another, it may be beneficial to assess the land ownership, land development charges, and other infrastructure before taking up installation of solar modules.

The solar PV plant shall be designed after consideration of shadows cast by WTGs. The empty zone required to avoid shadows from WTGs should be less than the safety zone of WTG and greater than the operating zone of WTG. It was found that this empty zone will avoid shadows during maximum generation time periods (10 am-4 pm), and minimal shadows early in the morning (before 10 am) and late afternoon (after 4 pm, in most western or southern states of India) during which time solar generation and temperatures are low, and therefore, the likelihood of hot spots caused in solar PV modules is also low.

5 OPTIMIZATION OF FINAL CAPACITY MIX FOR EVACUATION

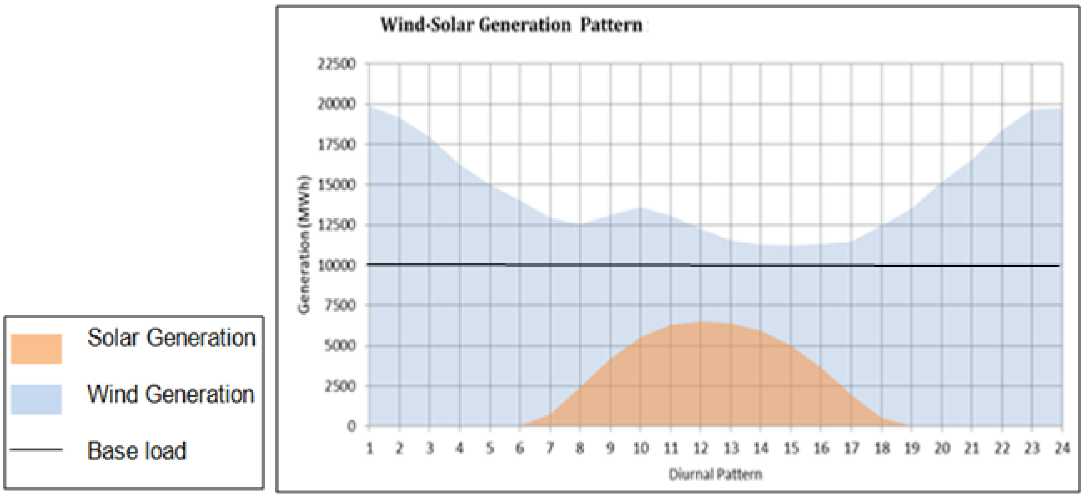
Annual energy prediction from the combination of wind and solar with different capacities of wind and solar shall be analyzed and energy curves should be assessed to find the best possible combination for the energy mix of the hybrid plant, which meets the project goals. Different scenarios shall be analyzed and best case decided, on the basis of the following goals for optimizing the capacity mix of wind and solar:

- Balance of Net Generation
    - Generation mix of solar and wind
- Generation Efficiency
    - Maximized net generation in kWh for the given area (kWh/m^2)
    - Minimized levelized cost of generation INR/kWh
- Variability
    - Peak to average generation/hour
    - Coefficient of variation of generation/ hour
- Transmission Efficiency
    - Maximum MWh/MW of transmission capacity.

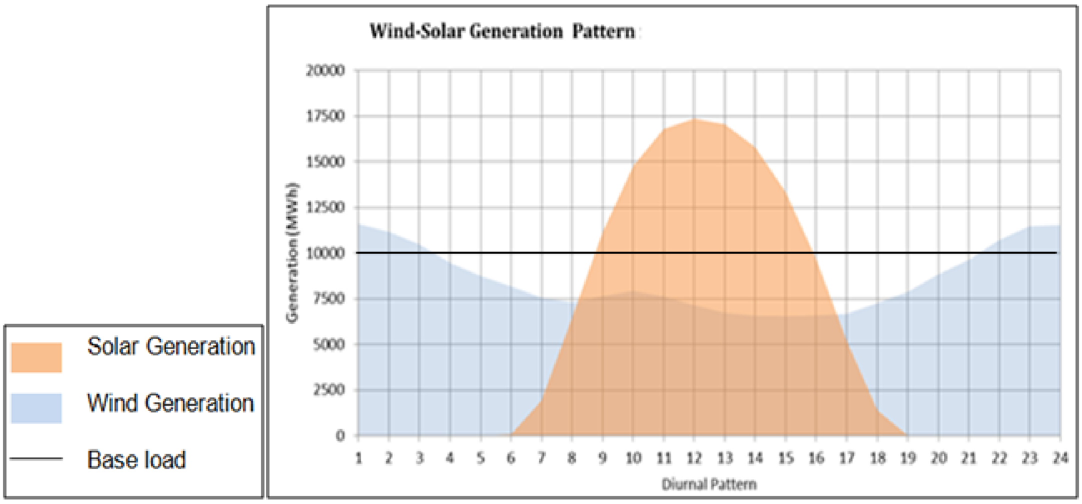
5.1 BALANCING NET GENERATION WITH DIFFERENT MIX OF WIND AND SOLAR CAPACITIES

Wind and Solar capacity mix would create different generation curves which can evaluate for balance.

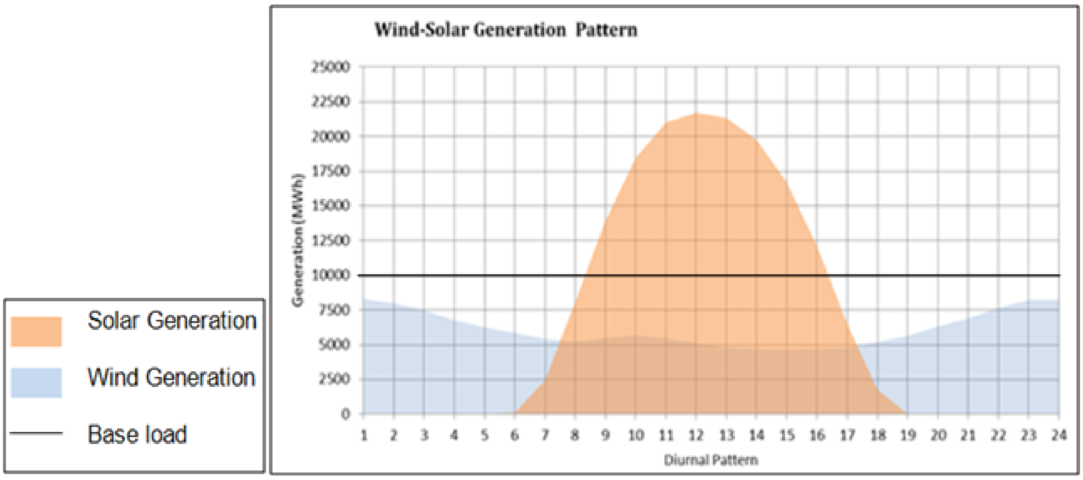
For example, three curves showing the generation pattern for three different capacity mixes and resulting in different generation ratios for wind and solar are given in Figure 5 for a site in Karnataka.



Case 1: Wind energy generation is much greater than solar generation



Case 2: Wind energy generation and solar generation are equal



Case 3: Solar energy generation is much greater than wind generation

Figure 5 Generation curves for different capacities of wind and solar

An appropriate mix would be chosen which delivers power closer to the customer load, if that is the goal.

5.2 LEVELIZED COST OF GENERATION (LCOE) AND ENERGY YIELD / m^2

The plant capacity mix can also be optimized for lowest delivered cost of energy. Table 9 provides the total generation values and LCOE values for a wind and solar hybrid plant of the site in Karnataka taken as a case study. Different configurations can be developed for solar PV on the basis of AC:DC ratio, pitch and tracker use after fixing the wind capacity configuration, similar to the ones developed during optimizing solar PV configuration for maximum generation. However, here the LCOE values change for every scenario of solar PV, while wind LCOE is kept the same, based on the fixed configuration of wind capacity.

Out of all the given scenarios it can be seen that scenario 7 with 10 degree tilt angle and 7.5 meter pitch for solar PV has the maximum generation of 605,360 MWh per year for wind-solar hybrid. It also has the lowest LCOE of 3.34 INR /kWh[15] of energy. Hence, it can be concluded that scenario 7 is the most optimized scenario as it ensures cost-effective utilization of land and resources to give maximum generation.

Table 9: Scenarios for hybrid LCOE and total energy generation

General					Land requirement /MW		Capacity Utilisation		Installed Capacity			Generation (MWh / Year)				LCOE (INR / KWh)		
S. No.	AC:DC ratio Solar	Angle (Degree)	Pitch	Tracker	Solar Acre/MWp	Wind Acre/MW	p50	p75	Solar - MWp	Solar - MW	Wind	Solar	Wind	Ratio of generation (s:w)	Total	Solar LCOE	Wind LCOE	Hybrid LCOE
1	1.3	10	7.5	Fixed	2.61	11.36	18.71%	36%	238.20	183.23	68	390417	214326	182%	604743	3.36	3.13	3.28
2	1.3	15	8.2	Fixed	2.79	11.36	18.78%	36%	222.90	171.46	68	366670	214326	171%	580996	3.36	3.13	3.28
3	1.3	20	8.9	Fixed	3.03	11.36	18.73%	36%	205.78	158.29	68	337686	214326	158%	552011	3.38	3.13	3.29
4	1.2	10	7.5	Fixed	2.52	11.36	18.71%	36%	247.66	206.39	68	405921	214326	189%	620247	3.40	3.13	3.31
5	1.2	15	8.2	Fixed	2.73	11.36	18.79%	36%	228.98	190.82	68	376899	214326	176%	591225	3.40	3.13	3.30
6	1.2	20	8.9	Fixed	2.94	11.36	18.74%	36%	212.96	177.47	68	349685	214326	163%	564011	3.42	3.13	3.31
7	1.35	10	7.5	Fixed	2.61	11.36	18.72%	36%	238.46	176.64	68	391034	214326	182%	605360	3.34	3.13	3.27

A similar analysis can be carried out for any Greenfield project to ensure maximum generation in the most cost-effective manner from the given land. This might differ slightly from project to project depending on whether cost or generation can be compromised to some extent. For example, for any project, the total generation from wind and solar for a certain capacity mix, could get maximized at the same scenario for solar, which does not have the lowest LCOE. In this case, the developer can choose a scenario with maximum generation with greater LCOE or less generation with lower LCOE. The developer can also choose a solution which lies in the middle, that is, both generation and LCOE are accounted for, and none of the two is given preference over the other.

5.3 PEAK TO AVERAGE GENERATION RATIO AND COEFFICIENT OF VARIATION

For choosing an optimized capacity mix of solar and wind for a hybrid plant, it is imperative to take the variability of energy generation from the hybrid plant into consideration in order to have a more stable grid. It can be ascertained from the peak to average energy generation ratio and coefficient of variation of energy generation from the resultant hybrid. The hybrid plant shall bring the peak energy curve closer to average energy curve and ensure the least variability in generation from the average generation.

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[15] Based on costs for solar and wind projects as observed in September 2017

An analysis of hourly generation patterns was carried out for a wind-solar hybrid site in Karnataka for wind installed capacity of 62 MW and solar installed capacity of 247 MW. The peak to average generation ratio and the coefficient of variation of generation was calculated for independent wind, independent solar and wind-solar hybrid. It can be seen in Table 10 and Table 11 that wind-solar hybrid balances the generation more optimally as compared to only solar, with the ratio of peak energy to average ratio and coefficient of generation less than solar, ensuring lesser fluctuations injected in the grid.

Table 10: Peak to average generation ratio

Parameter	Wind	Solar	Hybrid
Peak energy	220	758	976
Average energy	88.7	182.7	271.46
Peak to average ratio	2.48	4.15	3.5

Table 11: Coefficient of variation of generation

Parameter	Wind	Solar	Hybrid
Standard deviation of energy	71.9	246.46	251.07
Average energy	88.7	182.7	271.46
Coefficient of Variation	0.81	1.35	0.92

As the peak to average ratio decreases from 4.15 for solar to 3.5 for hybrid, i.e., the difference between peak energy and the average energy generation levels in case of wind-solar hybrid is reduced, better balancing of the grid is attained. Coefficient of variation, which is a ratio of standard deviation of generation to average generation, also follows the same trend, where it decreases from 1.35 in case of solar to 0.92 in case of hybrids. This shows that the relative variability in energy generation per hour is lesser in case of hybrid plants, leading to a more optimized energy generation curve.

Different scenarios should be analyzed and the best case decided on the basis of the following goals for optimizing the capacity mix of wind and solar:

- *Maximize Net generation in kWh form the given area (kWh/m^2) should be maximum*
- *Minimize Levelized cost of generation INR/kWh*
- *Reduce Peak to average generation ratio*
- *Reduce Coefficient of variation of generation*

6 Design of Common Services and Facilities

6.1 OPTIMIZATION OF POWER EVACUATION CAPACITY

At present, power generated from wind and solar projects is independently evacuated at the nearest sub-station and the approvals for evacuation capacity of solar or wind projects are usually given by the utility.

The wind-solar hybrid projects can serve as valuable assets for grid balancing as they exhibit less variability in generation curves and allow optimum use of infrastructure. In projects where wind or solar capacity is less than 30% of total, the smaller capacity can ride free on the evacuation capacity created for the larger capacity. To understand balancing impact across wind and solar we analysed a few scenarios for hybrid plants (162 MW solar and 60 MW Wind), which are shown in Appendix 4.

The analysis showed that when the power evacuation capacity reduces from 200 MW to 140 MW (from Scenario 1 to Scenario 7), generation losses increase from 0.08% to 5.96%, while the hybrid PLF increases from 31.3% to 42.0%. The table shows that for some loss in generation, significant savings can be obtained when power evacuation capacity is reduced. These generation losses and transmission savings have been estimated based on reduction of power evacuation capacity from 200 MW to 140 MW.

From the analysis, it is clear that selecting Scenario 4 with power evacuation at 170 MW is the most optimal capacity, where generation loss is within an acceptable range of 2% for the developers and PLF is also appreciable at 36.3%. The net savings in this project are at maximum (about INR 11.42 crore per annum) at 170 MW evacuation capacity. These savings will differ from state to state based on the transmission PoC rates present in the states, and hence, power evacuation capacity should be optimized to get maximum savings from minimum generation losses.

Power evacuation and metering in case of wind-solar hybrids is an important aspect to be taken into account, and Appendix 5 highlights a proposed architecture for metering.

We suggest AC side integration of solar and wind with common feeder lines to transport energy to the pooling substation. This will lead to savings in evacuation infrastructure costs.

In a wind-solar hybrid plant, against some loss in generation, significant savings can be obtained when power evacuation capacity is reduced to some extent.

A two level metering should be carried out for wind-solar hybrid plant at generator level and pre-pooling substation level, so that common evacuation infrastructure can be used for wind and solar to maximize savings from the hybrid plant.

6.2 USE OF ENERGY STORAGE

Energy storage use in conjunction with Hybrid plants can result in following benefits:

- Reducing transmission capacity further by storing surplus energy beyond the transmission capacity and releasing it when generation falls below the transmission capacity,
- Improving scheduling accuracy of power generation,
- Meeting peak load by shifting power generation to peak load period,
- Providing grid following service and control ramp up or down of the power and
- Providing ride through capability.

The use of energy storage requires a dedicated study and it is not the focus of this report. However, we are presenting below a brief analysis of the impact of energy storage with low transmission capacities and improved MWh/MW of transmission. MWh/MW can be improved from 2311 to 5769 (improvement of ~150%), reducing transmission costs significantly.

Table 12 Impact of Energy Storage on Transmission Efficiency, MWh/MW

	Analysis of Impact of Battery on MWh/MW Transmitted Transmission Capacity as % of Total Nominal Capacity				
		100.00%	**80.00%**	**60.00%**	**40.00%**
Battery Hours	**0.00**	2311	2883	3622	4515
	0.25	2311	2889	3708	4692
	1.00	2311	2889	3837	5161
	2.00	2311	2889	3852	5613
	3.00	2311	2889	3852	5769

Due to controlled transmission capacity, there is surplus energy left un-transmitted. This is reduced with energy storage as the table below indicates.

Table 13 Impact of Energy Storage on Surplus Power Un-transmitted

	Analysis of Impact of Battery in Reducing the Surplus Energy Transmission Capacity as % of Total Nominal Capacity				
		100.00%	**80.00%**	**60.00%**	**40.00%**
Battery Hours	**0.00**	0.00%	0.20%	5.96%	21.85%
	0.25	0.00%	0.01%	3.74%	18.79%
	1.00	0.00%	0.00%	0.37%	10.68%
	2.00	0.00%	0.00%	0.00%	2.84%
	3.00	0.00%	0.00%	0.00%	0.14%

It is evident that with 2-3 hours of battery storage, energy loss can be contained below 3%, even with transmission capacity kept at 40% of peak capacity.

Load firming can be observed in case of a wind-solar hybrid (capacity 190 MW solar, 60 MW wind), with 3 hour battery and transmission capped at 50 MW (20%).

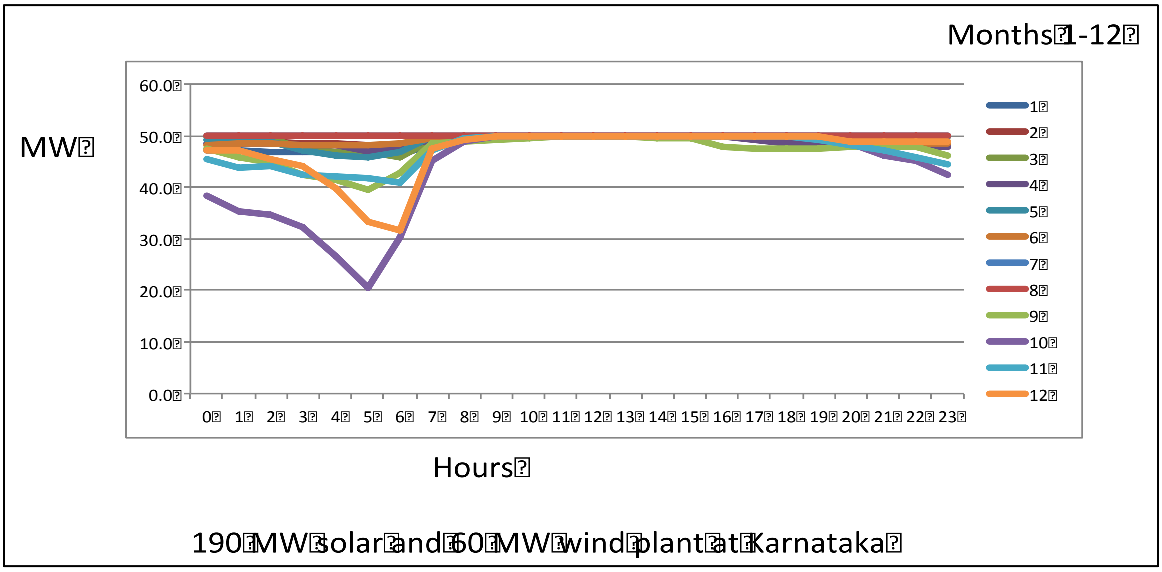

Figure 6 Load Firming with Energy Storage of 3 hours of peak capacity

Interestingly, with stringent transmission cap of 20% of peak, the plant is able to transmit 77% of power generated with 3 hour energy storage.

Our modeling however, indicates that high capital costs of energy storage at present makes its use uneconomical. Also, energy storage use is not beneficial till transmission of generated power becomes the responsibility of the generator.

7 Environment, Social and Governance (ESG) Framework for Wind-Solar Hybrid Projects

There are several ESG impacts linked with wind and solar power plant apart from the various benefits that should be identified and mitigated. ESG compliance is critical to ensure support from regulators, investors, employees, customers and partners.

ESG compliance is required to address the following:

- Compliance with laws relating to environment, health and safety, minimizing negative impact on environment, local community, and people employed in the operations
- Creating positive impact on the environment, community and people to ensure their continued support to the business, thereby enhancing support of all key stakeholders such as customers, partners, investors and employees for observing sustainable business practices
- Ensuring business responsiveness towards stakeholders

7.1 APPROACH FOR DEVELOPING ESG FRAMEWORK

Wind and solar projects are considered non-polluting, hence there are no stringent environmental norms exist for such projects. Yet, there are certain indirect impacts on environment and society.

While developing the ESG framework for wind-solar hybrid projects, the specific regulatory guidelines in India for both solar and wind were combined to generate a common theory to be followed by the hybrid project.

The following approach was followed while developing the framework:

1. Desk review of existing policies in environmental, health, safety and social management of on-shore wind and solar PV energy projects[16] in India
2. Analysis of impacts of wind-solar hybrid projects on various environmental, health, safety and social attributes
3. Identifying threshold criteria that need to be complied with by the solar and wind projects
4. Recommendations for sustainable governance and impact management

The ESG framework is divided into four components, as described below.

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[16] Information has been derived from government reports and various peer-reviewed journals and articles.

1. The first component lists down criteria related to the project site. Many of these criteria apply to all infrastructure projects and as a consequence apply to wind-solar hybrid projects also.
2. The second component of the framework lists down the guidelines for operation and management of the hybrid project from the perspective of impacts relating to waste, water use, noise, social welfare, impact on flora and fauna etc.
3. The third component of the framework provides direction for a strong governance mechanism that steers the business's operations in responsible manner.
4. The last component identifies other internationally acceptable ESG guidelines that are optional for domestically funded projects (India specific), yet are required if the business wants to be proactive in managing externalities and in cases where foreign funds are invested in the project.

All the four components are interlinked with each other, and may have certain common parameters and goals. These four components are described in Appendix 5.

8 CONCLUSION

The Wind-solar hybrid projects are found to be crucial upcoming technology to maximize the generation from the given land area and lowers cost of generation. Hybrid projects result in significant savings in terms of common capital expenditures like cost of land development, evacuation infrastructure, fencing, storage, and also operational savings in terms of plant security, maintenance team and administration personnel.

Hybrid generation also possess better balance (seasonal and diurnal) in the power supply curves, has less variability in generation and reduces transmission and evacuation costs.

The major steps involved in design of wind-solar hybrid project are:

a. Identify sites for a wind-solar hybrid after taking into consideration generation per unit area, delivered cost of energy and ESG norms. First, identify the sites rich in wind resource and then sites with optimum solar radiation shall be selected for hybrid zones.
b. Optimization of wind turbine placement and then solar module placement in empty to ensure least shadow loss and preventing hot spots. It is necessary to check that No shadows should fall on the panels between 10 am to 4 pm.
c. The final capacity of the hybrid project should be optimized based on one or more of goals related to delivered cost of energy, generation per unit area, grid balance, variable generation and transmission efficiency.
d. The power evacuation capacity of the hybrid can be optimized in order to get the benefit of net savings from reduction in transmission costs in comparison to the generation losses. One of the two (wind or solar) with installed capacity less than 30% can ride on the larger capacity, since wind and solar have complementary power generation pattern.
e. The norms pertaining to environment, social and governance parameters shall be ascertained and complied with while implementing a wind-solar hybrid project.

Energy storage can enhance the transmission efficiency and ability to meet the load curve. Economic case for use of energy storage would depend on relative value for meeting the load curve and reducing transmission costs versus capital and operating costs of energy storage.

For significant development of wind-solar hybrid projects, strong policy and regulatory support is necessary. The following areas need to be investigated for national policy:

- State Nodal Agencies (SNAs) should identify and acquire wind-solar resource rich site for development on park basis. A series of such pre-identified sites would improve investor confidence and reduce the development risks. At the same time, on such sites, only wind or only solar capacities shouldn't be allowed to set up.

- Incentives for wind-solar hybrid plants linked to their performance (e.g. PLF, peak to average ratio, MWh/MW transmitted etc.)
- Appropriate definition to capacity- it should be defined by transmitted power and not nominal peak capacity, to recognise the efficient transmission for wind solar hybrids.

Metering for wind-solar hybrids also should be allowed at multiple levels so as to use shared evacuation (internal). This issue has been analysed in a separate paper on Metering Approach for Wind Solar Hybrids.

APPENDIX 1: STATE WISE WIND-SOLAR HYBRID POTENTIAL IN INDIA

State	Area (in sq. km)	Solar PV Potential (GW)	Hybrid-capable Wind Potential (GW) at 120 m Hub Height	Hybrid Potential (GW)
Andaman and Nicobar	60	6.1	0.4	5.5
Andhra Pradesh	20,000	220	112	1,987
Arunachal Pradesh	2	0.2	0.2	0.2
Chhattisgarh	102	11	0.6	9.9
Dadra and Nagar Haveli	42	4.5	0.2	4.1
Daman and Diu	13	1.5	0	1.3
Goa	36	4.0	0.2	3,605
Gujarat	27,531	3,087	157	2794
Himachal Pradesh	6	0.5	0	0.5
Jammu and Kashmir	6,361	629	36	570
Karnataka	8,000	915	45	828
Kerala	80	9	0.5	7.8
Madhya Pradesh	22	2.5	0.1	2.1
Maharashtra	18,612	2,054	106	1860
Orissa	2,653	275	15	249.5
Puducherry	19	2	0.1	2
Rajasthan	15,230	1,705	86	1545
Sikkim	6	0.6	0	0.5
Tamil Nadu	3,331	380	19	344
Uttaranchal	973	94	5.5	85.5
West Bengal	3	0.3	0	0.2
India	**1,03,082**	**11,380**	**585**	**10,300**

Figure 7 Wind-solar hybrid potential state-wise[17]

[17] http://www.cstep.in/uploads/default/files/publications/stuff/CSTEP_Re-assessment_of_India%E2%80%99s_On-shore_Wind_Power_Potential_Report_2016.pdf

Appendix 2 Details of WTG and Solar Panel Placement

Wind Turbine Placement

According to the guidelines[18] provided by MNRE for Development of Onshore Wind Power Projects, following points shall be considered while optimization is carried out:

a. Turbine safety standards mentioned under IEC 61400-1 shall be considered while optimizing placement of wind turbine generator against extreme wind, flow inclination, vertical wind shear, turbulence and corrections for terrain complexity.
b. A minimum distance of 2 D perpendicular to the predominant wind direction and 3 D distance in the predominant wind direction from the boundary line of each adjoining land of other developer(s) must be maintained.

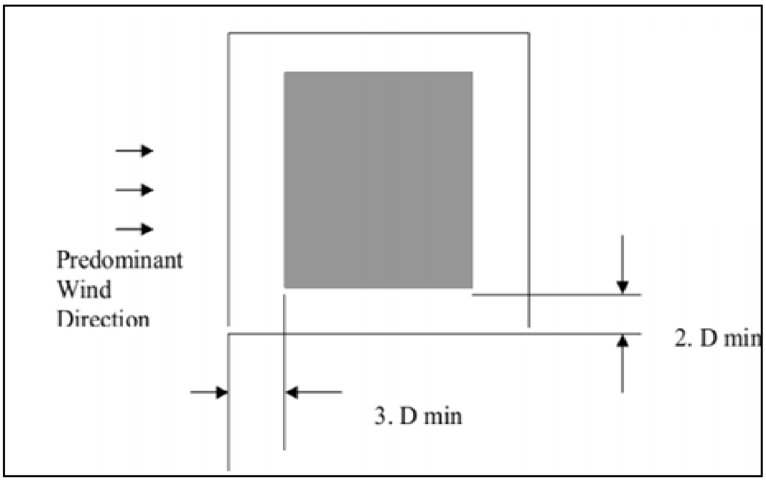

Figure 8 Distance to be maintained from boundary

c. Wake loss of 10% has to be maintained between turbines.

Micro-siting

Micro-siting is the optimization of energy production through appropriate placement of wind turbines after considering all the geographical and physical constraints. The wind turbines in a wind farm area are placed to achieve maximum energy production and minimum wake loss. This is carried out with the assistance of wind flow modeling, optimization tools (linear and non-linear) and associated techniques in any terrain conditions. The criteria for micro-siting of wind turbines is designed based on achieving an optimised output and not on the minimum distance between wind turbines.

It is mandatory to maintain a minimum distance of 3D (where D - Rotor Diameter), perpendicular to the predominant wind direction and a distance of 5D, parallel to pre-

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[18] http://mnre.gov.in/file-manager/grid-wind/Guidelines-for-Development-of-Onshore-Wind-Power-Projects.pdf

dominant wind direction, between wind turbines. For high wind areas, the turbines can be tightly placed, while taking the terrain of the land into account. More details about micro siting can be found in annexure 2.

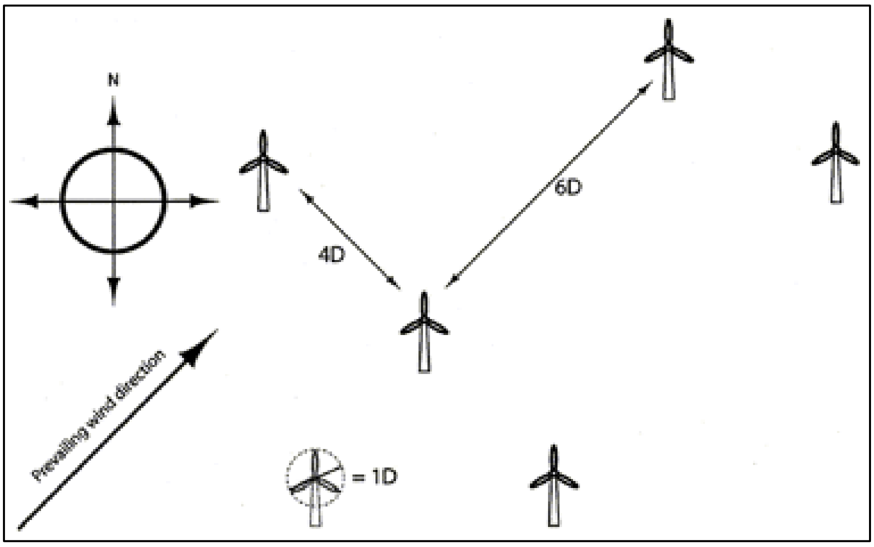


Figure 9 4D by 5D WTG configuration for WTG with rotor diameter D=100 m

Safety distance

While designing the wind micro-siting pattern, a few safety requirements need to be kept in mind. These include the following specific distances:

a. ***Safety distance for public infrastructure***: To maintain a distance of a minimum of HH+1/2 RD+ 5m (Hub Height+ Half Rotor Diameter +5 Meters) from public roads, railway tracks, highways, buildings, public institutions and EHV lines
b. ***Safety distance for public infrastructure***: A distance of 500m shall be maintained from any nearby dwelling to cut back the effect of noise

Taking the above conditions in consideration, site for installing wind turbines shall be decided, and energy generation optimized.

Annual energy prediction

The selection of wind turbine models and assessment of potential capacity of a wind farm are very important to determine the annual energy production from a wind farm. Wind turbine models need to be selected based on the Weibull distribution, roughness class and identification of wind class. The cut-in wind speed and rated wind speed need to be optimized, and the potential capacity of the site needs to be assessed based on the performance of wind turbines and land utilization per megawatt of capacity installed. The optimization of wind turbines is to be carried out based on gross energy yield, spacing criteria and existing terrain. The annual energy prediction from a wind farm should follow the following steps identified under Table 9.

Table 14 Methodology for Wind Energy Estimation

Project parameters review
⇩
Obtain data from available sources and check for authenticity
⇩
Identify data gaps and collect data during site visit
⇩
Derive long-term mean annual wind speeds at the site
⇩
Choice of simulation model and assumption for energy forecast
⇩
Carry out simulation to assess gross AEP
⇩
Correct AEP for long-term assessment

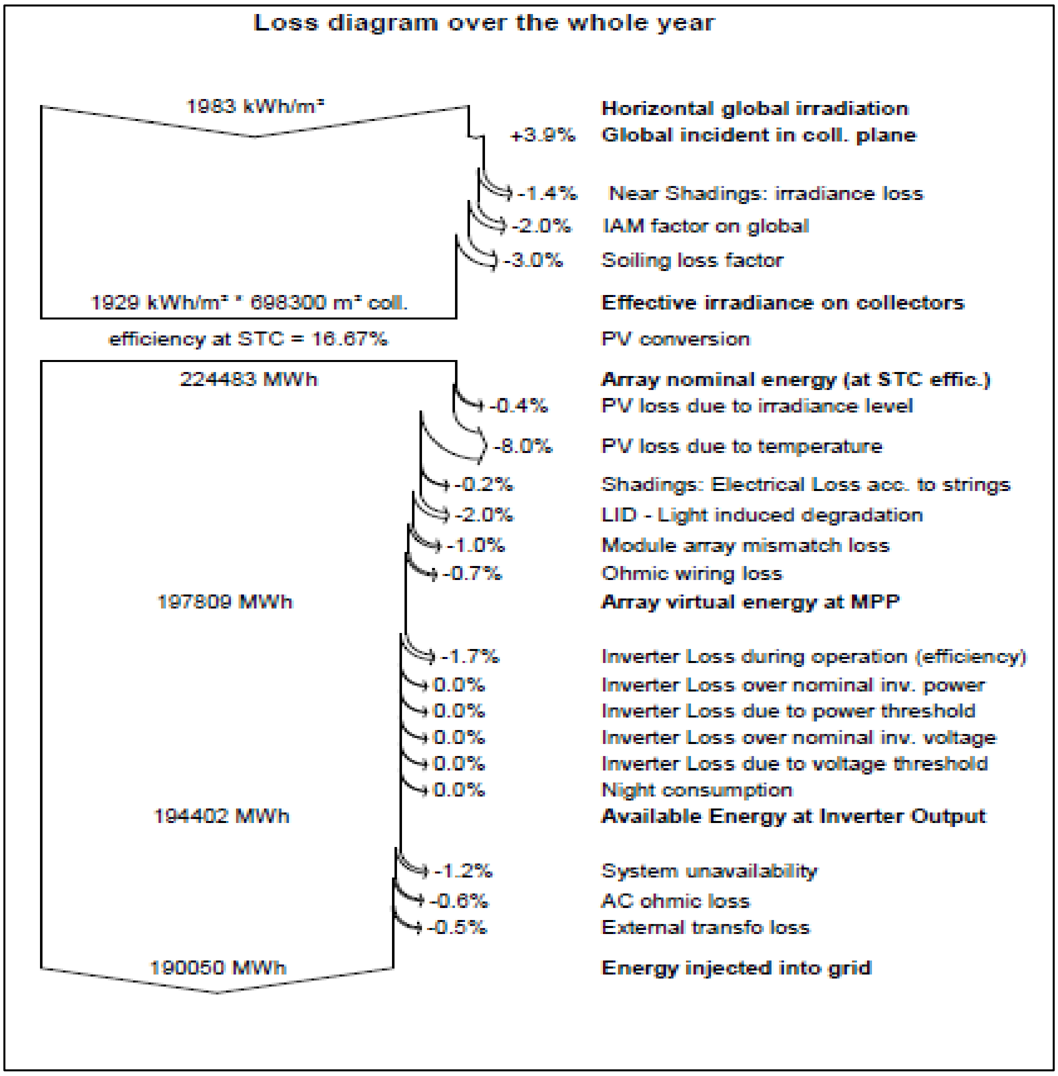
For long term energy yield assessment, correction factors shall be applied for various degrading parameters like blade soiling, machine availability, electrical efficiency, turbine performance retardation etc. In addition, various uncertainties shall be taken into account to estimate energy yield at various probabilities of exceedance (P50[19], P75 and P90).

[19] P denotes probability of exceedance. For example, P75 means 75% probability that energy yield in a year will exceed the P75 estimate.

APPENDIX 3 PVSYST SIMULATION REPORTS FOR SAFETY ZONE AND OPERATING ZONE

The following figures represent the analysis around installing solar modules in the safety and operating zone for the same site. Simulations were carried out for the empty area of 171 meters radius of safety zone of wind turbine (In line with MNRE guidelines) and for an operating zone squared area of 140 meters length from the wind turbine.

a. When the 171 meters radius area was kept empty with 30% DC loading, it was observed that the near shading loss was 1.4%. The solar capacity that can be installed here is 89 MW AC and energy generation from the total land is 190,050 MWh per annum.



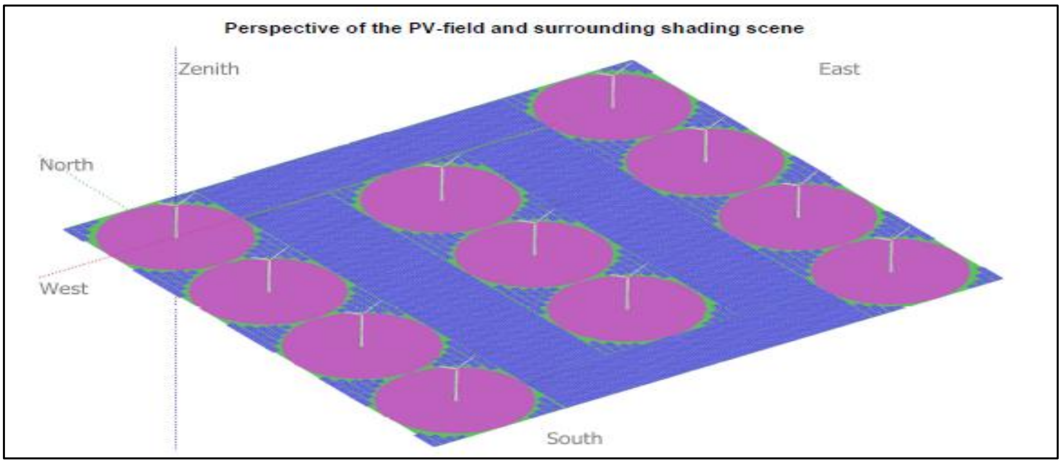
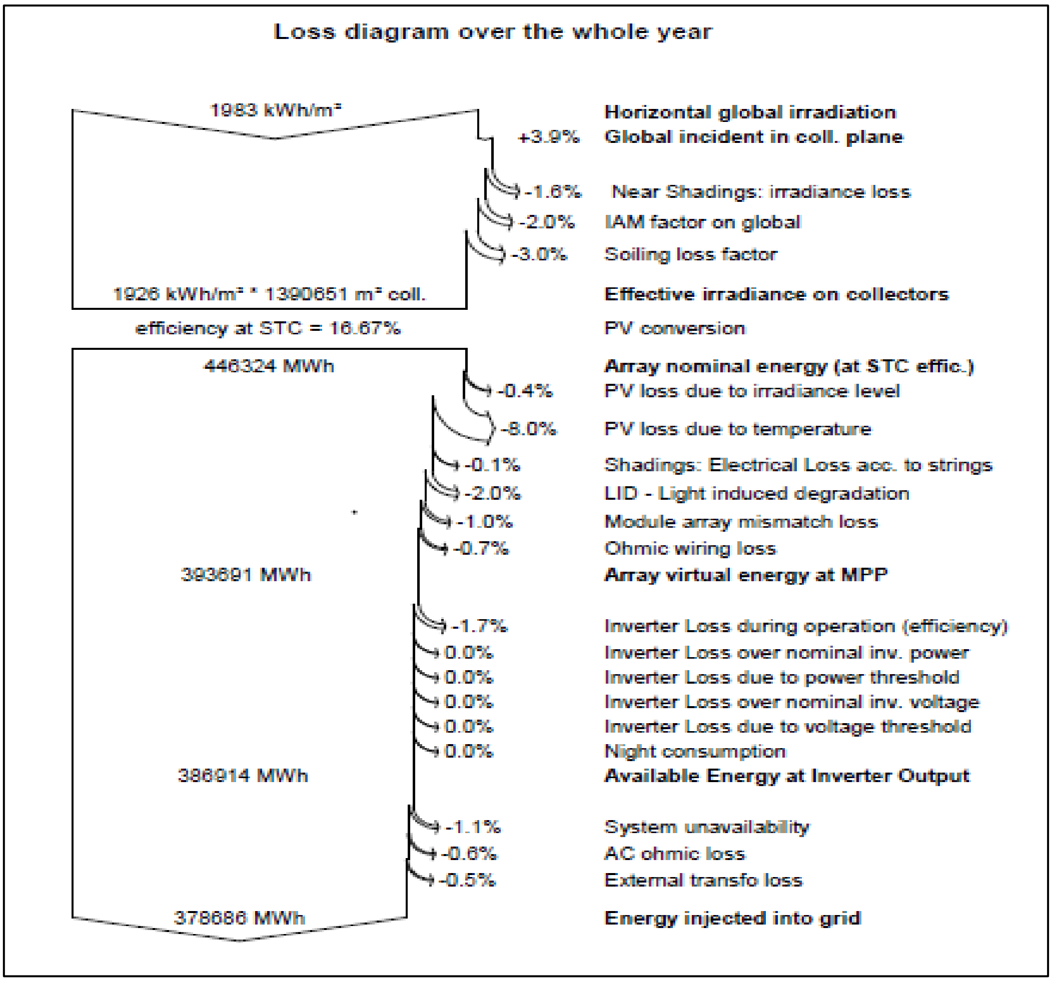


Figure 10 PVsyst simulation results for 171 meters safety radius

b. When the 140 meters length square area was kept empty with 30% DC loading, it was observed that the near shading loss was 1.6%, which is just 0.2% greater than in the case of 171 meters. The solar capacity that can be installed here is 178 MW AC and energy generation from the total land is 378,868 MWh per annum.

The shadows would not last long enough to create hotspots; however, an inverter should be capable of handling voltage fluctuation due to rotating blades. The analysis clearly shows a greater potential to pack solar, depending on land availability and the goals for balancing generation.



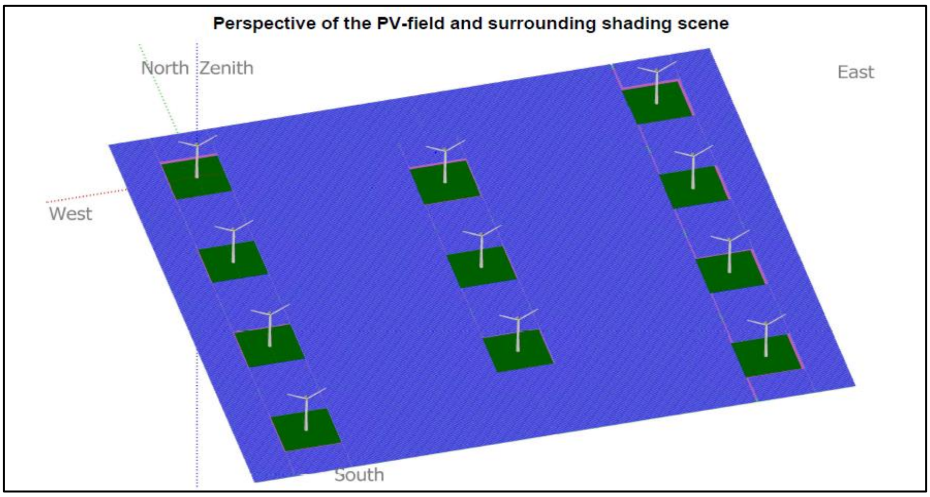


Figure 11 PVsyst simulation results for 85 meters safety radius

Appendix 4 Power Evacuation Capacity Analysis

Table 12 depicts the analysis for a wind-solar hybrid plant with AC capacity of 222 MW with 60 MW wind and 162 MW solar in Karnataka, and varying power evacuation capacity. Seven different scenarios with different evacuation capacities of wind and solar were identified to compare the generation values, losses in generation and instances of overloading of power evacuation infrastructure.

Table 15 Wind-solar hybrid scenario analysis

		Wind & Solar - Hybrid Analysis for Ramagirri, Anantpur, AP								
		PE (MW)	Wind Gen (MWh)	Solar Gen (MWh)	Total Gen (MWh)	Generation loss (MWh)	**% loss**	Net Gen (MWh)	Gen losses (INR)*	PE Savings (INR)**
Scenario #1	Value	**200**	202695	345439	548134	459	0.080%	547675	-	-
	PLF %	-	39%	18%	-	-	-	31.3%	-	-
Scenario #2	Value	**190**	202695	345439	548134	1448	0.260%	548009	4,344.00	38,082,840.00
	PLF %	-	39%	18%	-	-	-	32.9%	-	-
Scenario #3	Value	**180**	202695	345439	548134	3420	0.620%	544714	10,260.00	76,165,680.00
	PLF %	-	39%	18%	-	-	-	34.5%	-	-
Scenario #4	Value	**170**	202695	345439	548134	6903	1.260%	541232	20,709.00	114,248,520.00
	PLF %	-	39%	18%	-	-	-	36.3%	-	-
Scenario #5	Value	**160**	202695	345439	548134	12777	2.330%	535357	38,331.00	152,331,360.00
	PLF %	-	39%	18%	-	-	-	38.2%	-	-
Scenario #6	Value	**150**	202695	345439	548134	**21382**	3.900%	526752	64,146.00	190,414,200.00
		-	39%	18%	-	-	-	**40.1%**	-	-
Scenario #7	Value	**140**	202695	345439	548134	326272	5.960%	515462	978,816.00	228,497,040.00
	PLF %	-	39%	18%	-	-	-	42.0%	-	-
NOTE:										
For Wind analysis: Best 20 WTG locations has been identified. (Considering D=114m of Gamesa G114-2MW machine)										
For Solar analysis: AC/DC ratio has been considered as 1.35										
For PE Optimization: Over-loading events have been identified considering the limit above 100% of PE capacity										

*Considering hybrid tariff of INR 3.00 per kWh

**PE Savings from reduction in Point of Connection (PoC) transmission rates for Karnataka where PoC slab rate for Andhra Pradesh for Long Term Access = 317357 INR/ MW/ Month[20].

Note:

1. All figures are based on annual estimates.

[20] http://cercind.gov.in/2017/orders/44_L.pdf

2. The estimates are based on the assumption that the hybrid plant would have controller to ensure that the total output from the plant doesn’t exceed the power evacuation capacity (rated capacity)

*3. Hybrid PLF calculated as = Net generation/Rated capacity (Power evacuation) capacity*8760*

APPENDIX 5: PROPOSED METERING ARCHITECTURE FOR WIND-SOLAR HYBRID SYSTEM

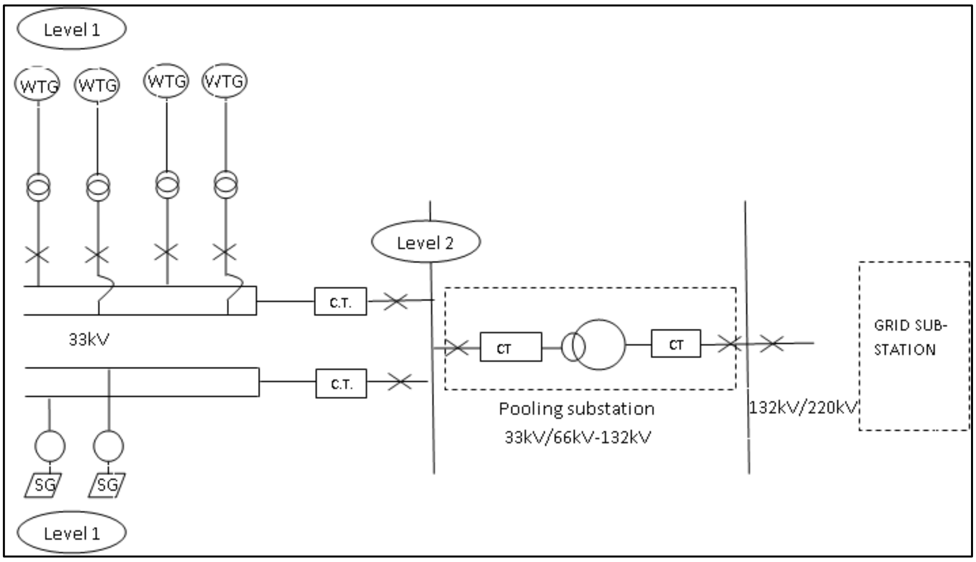


Figure 12 Metering approach

This is an important way to optimize power evacuation infrastructure and therefore the policy should encourage this mode, where the metering occurs at two levels:

Level 1: At wind turbine generator level for wind power plant (WPP) and at block level for solar power plant (SPP).

The availability based tariff (ABT) meter should be installed on each turbine/solar block.

Level 2: At pre-pooling substation level.

The losses at the pooling substation level can be calculated as:

$$Losses\ L(at\ pooling\ SS) = \frac{\sum_1^N (Ms, Mw) - Mt}{\sum_1^N (Ms, Mw)}$$

$$Solar\ Generation = Ms \times (1 - Losses)$$

$$Wind\ Generation = Mw \times (1 - Losses)$$

Where,

M_t - Total delivered energy at pre pooling substation

M_s - Total solar power generated at block level

M_w - Total wind power generated at wind turbine/block level

N – Number of WTG/solar blocks

This metering approach can be used for projects across all modes of integrated, hybrid level metering including:

a. Schemes where DC side of solar and wind generators are integrated and the output from a hybrid plant would be treated as a single output.
b. AC side outputs from wind and solar blocks are integrated. The integration can be carried out in these two modes
    - **Mode B1:** In this mode feeder lines to the pooling substations don't mix wind and solar output.
    - **Mode B2:** in this mode, common feeder lines take electricity generated from wind turbines and solar blocks, to the pooling substation.

APPENDIX 6 DETAILED ESG FRAMEWORK

PART 1: 'MINIMUM QUALIFICATIONS' FOR SITING HYBRID PROJECTS

The bare minimum criteria that need to be met for siting hybrid projects are listed in Table 13. ESG aspects are listed and related regulations are mentioned to help the project developers decide whether the specific location can be used for developing the project or not.

Table 16 Insurmountable situation/criteria

	Minimum distance of the wind-solar hybrid to be maintained (in meters)
ENVIRONMENTAL ASPECT	
Forests and forest land	No minimum distance from such land/area defined Permission for project depends on the state government
Wetlands	-
Sites of community importance	-
Special Protection Area	Depends on the state government
Lakes	500m[21]
Rivers	500m[22]
Seashore	500m[23]
Agriculture Land	0m
Quarrying-Mining Activities	-
SOCIAL ASPECTS	
Cities and Settlement (Residents)	Developer(s) shall not site wind turbines within 500m of any dwelling (for the mitigation of noise)[24] MoEF & CC guideline state that a minimum distance of 300m is recommended between windmill and highways or village habitation[25]
Traditional Settlements	-
Monasteries	200 m[26]
World Heritage Sites	-
Cultural Monuments and points	200 m[27]

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[21] http://envfor.nic.in/legis/crz/crznew.html
[22] http://envfor.nic.in/legis/crz/crznew.html
[23] http://envfor.nic.in/legis/crz/crznew.html
[24] http://mnre.gov.in/file-manager/grid-wind/Guidelines-for-Development-of-Onshore-Wind-Power-Projects.pdf

[25] http://re.indiaenvironmentportal.org.in/files/file/Green%20Norms%20for%20wind%20power%20full.pdf
[26] http://cpwd.gov.in/Publication/ConservationHertBuildings.pdf
[27] http://asi.nic.in/pdf_data/7.pdf

	Minimum distance of the wind-solar hybrid to be maintained (in meters)
of historical importance	
SAFETY ASPECTS: Proximity to (any) infrastructure	
HV Electricity Grid	Developer(s) shall maintain a distance of HH + 1/2 RD + 5m (Hub Height + ½ Half Rotor Diameter + 5 meters)[28]
Main Roads	Developer(s) shall maintain a distance of HH + ½ RD + 5m (Hub Height + 1/2Half Rotor Diameter + 5 meters)[29]
Aviation Facilities	No wind turbine generator/s shall be installed up to a distance of 10 KM in line of sight of the radar antenna of all Static Air Defense Radars and up to 8 KM from VOR and Airport Surveillance Radar (ASR)[30]
Harbors	500m[31]

The above table will help the project proponent to filter locations and decide upon whether to go ahead or abandon the project.

PART 2: EHS GUIDELINES FOR SOLAR-WIND HYBRID PROJECTS

The negative externalities associated with project construction and the operation phase has been classified under the following parameters:

a. Water contamination
b. Waste generated
c. Noise produced
d. Project impact on environment and wildlife
e. Exposure of the community to health and safety issues
f. Social welfare of the community

Depending on the type of impact of the project, and the regulatory mechanism prescribed for either solar or wind projects, a mitigation action list is prepared that can be used by the wind-solar hybrid project proponent to conform to the EHS norms of the country.

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[28] http://mnre.gov.in/file-manager/grid-wind/Guidelines-for-Development-of-Onshore-Wind-Power-Projects.pdf
[29] http://mnre.gov.in/file-manager/grid-wind/Guidelines-for-Development-of-Onshore-Wind-Power-Projects.pdf
[30] http://www.civilaviation.gov.in/sites/default/files/gsr%20751%20dated%2030.9.2015%20English.compressed.pdf
[31] http://envfor.nic.in/legis/crz/crznew.html

Water conservation and management: Water is required during the project construction phase and also during the e of the wind-solar hybrid project. The quantity of water required will be determined by the size of the project.

Related regulation in the country: Water use and management is controlled and guided by the Water Prevention & Control Act, 1972. This Act provides for the prevention and control of water pollution and for the maintenance or restoration of water.

Potential impact	• Local ground/ surface water depletion (if water is withdrawn from aquifer) • Surface and ground water contamination
Actions required[32]	• Guidelines issued for water harvesting and reuse by states for renewable farms are to be abided with • In cases where ground water is to be used for the project activity, permission from State Ground Water Board (SGWB) is required

- **Waste management:** Waste and scrap material is generated from erection of structures and related construction activities. Also, waste is generated during equipment maintenance and vehicle use on the site (waste could include discarded lubricating oil, hydraulic and transformer oils etc.).

Related regulation in the country: The laws governing the waste management practices at the wind-solar project site are:

- Hazardous Wastes (Management, Handling and Trans-boundary Movement) Rules, 2008
- Municipal Waste Management Rules, 2000
- E-waste Management Policy, 2011

Potential impact	• Contamination of water, soil or negative impact on local habitat.
Actions required[33]	• Hazardous waste such as spent lubricating, hydraulic and transformer oils should be collected and disposed of through an authorized dealer[34] • Scrap material generated from erection of structures and related construction activities has to be collected and stored separately in a stack yard and sold to local recyclers[35] • Users have to ensure that e-waste generated by them is

[32] Source - http://www.envfor.nic.in/legis/water/wat1.html , http://www.cgwb.gov.in
[33] Source - http://www.envfor.nic.in/legis/water/wat1.html , http://www.cgwb.gov.in
[34] http://www.cpcb.nic.in/HWM_Rules_2016.pdf
[35] http://www.moef.nic.in/legis/hsm/mswmhr.html

	channelized through a collection center or dealer or dismantler or recycler or through the designated take back service provider of the producer to authorized dismantler or recycler[36]
Reporting	• Reporting to State Pollution Control Board (SPCB) on disposal of hazardous waste

- **Noise control:** The wind-solar hybrid project would produce noise during the construction phase and operation phase (a wind turbine produces both high and low frequency noise). It is broadband in nature and is distributed over a wide frequency spectrum that ranges from infrasound to ultrasound [<20 Hz – >20 kHz]).

Related regulation in the country: The Noise (Regulation & Control) Rules, 2000 were amended in 2010 and the following noise levels are currently prescribed for industries

Table 17 Noise levels as prescribed for industries

SN	Category of area/zone	Day time limit in dB(A)	Night time limit in dB(A)
1	Industrial area	75	65
2	Commercial area	65	55
3	Residential area	55	45
4	Silence zone	50	40

Potential impact	• Effect of noise on communities living in the vicinity of the project
Actions required	• When communities are located within a 1.0 km radius, noise and shadow flickering studies are required

- **Wildlife and biodiversity**

The wind-solar hybrid projects are likely to have direct implications on the quality of the environment of the region where they are established.

Some of the potential impacts on biodiversity could be habitat fragmentation and loss, injuries to and mortality of birds and bats, wildlife mortality due to electrocution, disruption of canopy continuity for arboreal animals in closed-canopy forests, cutting of vegetation resulting in weed proliferation and suppression of native vegetation

[36] http://www.moef.gov.in/sites/default/files/EWM%20Rules%202016%20english%2023.03.2016.pdf

regeneration. Specific to the wind component of the project, the movement of the blades is an obstruction for birds and bats.

Related regulation in the country: The law that governs the environmental impacts of the wind-solar hybrid project is Forest (Conservation) Act, 1980.

Potential impacts	• Loss of top soil • Loss of habitation of flora and fauna • Disruption to free movement of wildlife • Disruption to movement of birds/bats • Disruption to movement of birds can have a high impact if the wind farms are on the movement corridor of such species • Perceived conflict with local community if common resources are put to commercial use. • Loss of land / and other physical assets • Loss of livelihood • Loss of access rights • Loss of common property resources
Actions required[37]	• Clearance is required for forest diversion, but no EIA is required. • Projects should not be considered in national parks and sanctuaries, areas of outstanding natural beauty, important landscape, and natural heritage sites etc. • National Board of Wild Life (NBWL) clearance is required if project falls under eco-sensitive zone around national parks and wildlife sanctuaries • Check/ test for erosion and water body impact • To reduce/ avoid bird hit, tips of the wind turbine should be painted with orange color
Reporting	No mandatory reporting

- **Health**

The health component of the framework addresses five types of direct and indirect implications of the project on the health of humans dealing directly with the project (construction, operation and maintenance) or living/ operating in the vicinity of such projects.

a. Quality of water and its availability
b. Structural safety and threats posed by the infrastructure
c. Direct or indirect threat to life and fire safety issues
d. Disease prevention
e. Traffic safety (especially during the construction phase of the project)

[37] Source - http://www.envfor.nic.in/legis/water/wat1.html , http://www.cgwb.gov.in

- **Water quality and availability:** Project activities involving wastewater discharge, water extraction, diversion or impoundment

Potential impact	• Adverse impacts on quality and availability of ground water and surface water
Mitigating actions[38]	• Project activities should not compromise the availability of water for personal hygiene needs and should take account of potential future increases in demand
Reporting	• No mandatory reporting

- **Structural Safety of Project Infrastructure**

Related regulation in the country: The National Building Code of India (NBC). The code mainly contains administrative regulations, development control rules and general building requirements, fire safety requirements, stipulations regarding materials, structural design and construction (including safety), building and plumbing services, approach to sustainability, and asset and facility management[39].

Potential impact	• Physical trauma associated with failure of building structures • Injuries due to consequence of falls or contact with heavy equipment
Mitigating actions[40]	• Physical separation around project sites to be ensured to protect the public from major hazards • Incorporation of siting and safety engineering criteria to prevent failures due to natural risks
Reporting	• No mandatory reporting

- **Life and Fire Safety**

Emergency preparedness and response	• Emergency plan to be prepared and staff well trained through mock-drills and trainings
Fire - prevention, safety and response[41]	• Fire Extinguisher and First-Aid Box should be provided or kept on site as per requirement • Adequate provisions should be made to avoid fire hazards due to short-circuiting in substation and switchyard • Fire safety design and fire-fighting equipment consistent with national standards to avoid fire hazards from transformers/ sub-stations should be made available

[38] Source - http://www.envfor.nic.in/legis/water/wat1.html , http://www.cgwb.gov.in
[39] http://www.bis.org.in/sf/nbc.htm
[40] Source - http://www.envfor.nic.in/legis/water/wat1.html , http://www.cgwb.gov.in
[41] Source - http://www.envfor.nic.in/legis/water/wat1.html , http://www.cgwb.gov.in

	• Preparation of fire emergency action plan and relevant staff training should take place
	• The rotor blade should be equipped with lightening protection system. The lightening receptor should be connected to the hub and nacelle and proper earthing should be made
	  o Electric shock hazards
	  o Restrict entry to substation area
	  o Appropriate color coding and warning signs on facilities
	  o Prepare emergency plan to avoid unforeseeable events and/or natural calamities
	• The SPV plant shall be equipped with suitable fire protection and firefighting systems for protection of entire equipment switchyard and control room as per CEIG requirements
	  o Minimum requirements for fire protection in the event of internal faults shall be in accordance with IEC 60695-2-11
	  o In order to avoid the fire hazard due to possible DC arcing in the SPD due to operation of thermal disconnector, the SPD shall be able to extinguish the arc
	  o The SMU enclosure shall be fire retardant with self-extinguishing property and be free from halogen
	  o All cables shall meet the fire resistance requirement as per IEEE - 383 with cable installations made in accordance with 'Flammability Test' and as per Category-B of IEC 332 Part -3

Safety against fall/injuries	• For working at a height of 50-80m, as good practice, risk assessment should be undertaken, if wind turbines are located within 50–200m of a public road
Traffic safety	• Traffic safety should be promoted by all project personnel during displacement to and from the workplace, during operation of project equipment on private or public roads
Disease prevention-response to labor mobility linked communicable diseases	• Guidelines to control vector-borne diseases as prescribed by the relevant health department • On site availability of doctor and provisioning of first aid services

- **Occupational health and safety in the wind-solar hybrid project:** The guidelines address the safety concerns during construction and operation phase of the project.

Related regulation in the country: Central Electricity Authority (CEA), Building and Construction Workers Act 1996, Workers Compensation Act, Employer Liability Act, and Contract Labor Rule

Possible impacts	• Health and safety of workers, concerns for workers and society due to siting of windmills near utilities and human habitation
Mitigating actions	• Health and Safety Guideline for Construction and Operation of the wind farm are to be followed (wind farm norms are stricter than the norms for the solar farm) • Safety requirement for operation, construction and maintenance of electric plans and electric lines are to be complied with

- **Solar wind hybrid project: Guidelines for addressing social concerns**

The wind-solar hybrid project will require approximately 3-5 acres of land per MW. The land may be revenue land or private land.

Related regulation in the country: Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act.

Possible impacts	• Wind-solar hybrid project development changes the land use • Perceived conflict with local community, if common resources are put to commercial use • Conflict over resources and use of forest or agricultural land between locals and wind-solar hybrid developers may occur
Actions required	• Conduct public consultations, both to determine local land use, identify potential concerns of nearby residence • No-objection certificate from district collector for setting up the project • No-objection certificate from the local Panchayat • Mandatory consent from the community is required with following specifications: o 70% of affected people for acquiring land for Public Private Partnership (PPP) projects o 80% for acquiring land for private companies • For projects coming up in forested areas: o Land that is identified in forest areas can be

	acquired only on lease basis and subject to clearances from the forest department

Conclusion: The ESG framework for the wind-solar project has been designed by considering the different guidelines for both solar and wind projects, and the laws governing any infrastructure projects being developed in the country. The ESG thresholds are defined by considering prescribed limits as mentioned in the various Government Acts governing such projects.

PART-3: GOVERNANCE GUIDELINES FOR THE WIND-SOLAR HYBRID PROJECT

The business governance aspects are partially covered under the Company's Act in the country. These include aspects linked to the rights and responsibilities of the management of the business/company. The guidelines ensure that the company's dealings with its stakeholders and shareholders are clearly laid out.

Under the governance aspect, following is expected from a company:

1. Management structure: The decision making within the company and the role of board should be clearly defined. Further, E&S management functions (or ESG systems) should be described in detail and associated responsibilities assigned and reflected in the key performance indicators of the management.
2. Human resource management: The Company should have a clear and detailed HR policy in place that highlights company's responsibilities towards its staff and ensures an equitable and just environment for everyone.
3. Commitment towards ESG concerns: The Company should have an E&S/ ESG policy in place that provides direction to the company in its operations and dealings with stakeholders (including contractors and sub-contractors).
4. Reporting and voluntary disclosures: The project developer/company should have clear policy to report Company's performance on the E&S parameters. Apart from the mandatory reporting, a proactive company should be periodically reporting company's E&S performance on voluntary parameters as well.

PART- 4: OTHER E&S ASPECTS FOR INTERNATIONALLY FUNDED WIND-SOLAR HYBRID PROJECT

The wind-solar hybrid projects funded by non-domestic sources would have to abide by the financer's E&S guidelines. Some important guidelines like, IFC's Environment Health Safety Guidelines for Wind Energy, European Investment Bank's Statement on Environmental and Social Principles and Standards, Asian Development Bank's safeguards, etc. are described below:

- **IFC Performance Standards:** International Finance Corporation's (IFC's) Performance Standards on Environmental and Social Sustainability include environmental and social parameters categorized under 8 aspects like labour and working conditions, community health, safety and security, resource efficiency and pollution prevention.

- **ADB safeguards:** Asian Development Bank (ADB) has safeguards for environment, involuntary resettlement and indigenous people, further divided into categories based on the significance and impacts.

- **Equator Principles:** Equator Principles are used by financial institutions to assess the social and environmental risks associated with a project.

- **KfW standards:** KfW Development Bank has a set of minimum requirements relating to social and environmental parameters, for any contract for goods, services and associated works. These ensure social and environmental sustainability of all the projects and programs financed by the German Financial Corporation.

IFC guidelines are most widely used by the financers and project developers to measure and communicate E&S compliance, which is further elaborated below:

The applicable IFC Performance Standards (2012 version) for due diligence E&S parameters are categorized under eight (8) aspects. Each of these aspects is defined in the following sections.

SN	Performance Standard	Description
1	Performance Standard 1	Assessment and Management of Environmental and Social Risks and Impacts
2	Performance Standard 2	Labour and Working Conditions
3	Performance Standard 3	Resource Efficiency and Pollution Prevention
4	Performance Standard 4	Community health, Safety and Security
5	Performance Standard 5	Land acquisition and involuntary resettlement
6	Performance Standard 6	Biodiversity conservation and sustainable management of living natural resources
7	Performance Standard 7	Indigenous people
8	Performance Standard 8	Cultural heritage

Part of the parameters that need to abide with under IFC guidelines are common to the E&S framework described for projects developed in India. In particular with IFC guideline, there are specific aspects that need to be complied with during the installation and operations phase of the solar wind projects.

PS1-Social and Environmental Assessment and Management System: Some of the key assessments include:

- Landscape

- Noise
- Pre project Environment and Social Impact Assessment exercise to be carried out to develop the baseline. Specifically to wind-farm, shadow flicker is to be prevented or control measures to be applied

PS2-Labour and Working Conditions: Apart from general working conditions, specific to wind projects standard operating procedure are to be carried for following:

- Working at Height
- Working over Water
- Working in Remote Locations
- Lifting Operations

PS3-Resource Efficiency and Pollution Prevention: The IFC guidelines focus on total avoidance or minimization of the negative adverse impacts on human health and the environment by avoiding or minimizing pollution from project activities. This is done by:

- Promoting sustainable use of resources, including energy and water.
- Reduction of project-related GHG emissions.

PS4-Community Health Safety and Security: The IFC guideline is quite elaborate when dealing with the health safety and security aspects of the project activity. The guideline specifically focuses on:

- Anticipation and avoidance of adverse impacts on the health and safety of the Affected Community during the project life from both routine and non-routine circumstances.
- Ensuring and safeguarding of personnel and property is carried out in accordance with relevant human rights principles and in a manner that avoids or minimizes risks to the Affected Communities.

PS5-Land Acquisition and Involuntary Resettlement: The IFC prescribes highest standards for ensuring the fair practice of land acquisition and resettlement is followed while developing projects. The IFC guideline suggests avoidance of any land acquisition from community and in cases where it's not possible to avoid displacement; guidelines are to be followed to ensure that fairness is observed to compensate economic losses linked to displacement. In addition, adequate housing and land tenure security of the displaced people is to be ensured by the project developer.

PS6-Biodiversity Conservation and Sustainable Natural Resource Management: The guidelines focus on preserving the quality of ecosystem services and biodiversity of the project locality and provide direction to help integrate conservation needs and development priorities.

PS7-Indigenous People: The sites and company's operations should not adversely impact indigenous people. Apart from related to human rights and cultural aspects, the IFC guidelines also provide directives for getting consent from the affected indigenous people and respecting and preserving the cultural knowledge and practices of indigenous people.

PS8-Cultural Heritage: The IFC guidelines are designed to ensure that the project should not adversely affect the cultural heritage in the immediate vicinity of the project site and equitable sharing of benefits from the use of cultural heritage.

The specific obligation/guideline for the project developers are clearly defined by the IFC for each of the eight aspects. Projects seeking IFC/EIB foreign financing have to strictly abide by these guidelines, these guidelines are very comprehensive and ensure high performance of project on E&S parameters, thus favoured and accepted by other foreign investors as well.

Appendix 7 Brownfield wind-solar hybrid projects

1. *Site identification*

Brownfield projects already have a lot of infrastructure, including roads, telecommunication, water linkage, power evacuation, impact on local community and ease of development etc. taken care of. For Brownfield projects, solar and wind energy resource availability along with adequate empty land and adequate power evacuation capacity availability shall be the major factors while defining the capacity for hybridization, and for maximizing energy generation and ensuring low delivered cost of energy generation.

2. *To place solar PV modules in existing wind farm/ To place WTGs in existing solar park*

Brownfield projects with WTGs already installed, it is ideal to carry out wind micro-siting first. Solar PV modules shall only be placed in the shadow free area of wind turbines after shadow analysis. For uneven lands, where WTG placement is done in a contiguous manner at a very large distance from one another, it may be beneficial to assess the land ownership, land development charges, and other infrastructure before taking up installation of solar modules.

For Brownfield projects where solar PV modules are already installed, wind turbine placement to maximize generation will be possible only when certain modules are removed. Also wind speed may be ideal for generation in certain pockets on the site, so a similar micro siting process as highlighted above will need to be carried out for Brownfield projects as well.

3. *LCOE*

Different configurations can be developed for solar PV on the basis of AC:DC ratio, pitch, tracker after fixing the wind capacity configuration, similar to the ones developed during optimizing solar PV configuration for maximum generation. However, here the LCOE values change for every scenario of solar PV, while wind LCOE is kept the same, based on the fixed configuration of wind capacity.