Pakistan Sustainable Energy Series

Variable Renewable Energy Locational Study

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Front cover: First wind power project by FFC Energy at Jhimpir, Sindh Province, which kickstarted the renewable energy revolution in Pakistan.

Back cover: Zonergy 300 MW Solar PV Plant at Quaid-e-Aʒam Solar Park, Bahawalpur, Pakistan.

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ACRONYMS AND GLOSSARY

AC	Alternating Current
AEDB	Alternative Energy Development Board
BOOT	Build, own, operate and translate
CDP	Common Delivery Point
CF	Capacity Factor
CPPA	Central Power Purchasing Agency
DC	Direct Current
DISCO	Distribution Company
EHV	Extra High Voltage (above 230 kV)
EPC	Engineering, procurement and construction
FESCO	Faisalabad Electric Supply Company
Financial Attractiveness	The "financial attractiveness" is a relative score based on the expected price of electricity (PPA rate) for a specific POA at which a developer would build and operate a plant. It is based on a scale of 1 to 10, with 1 being the least attractive case (highest cost of energy) and 10 the most attractive case (lowest cost of electricity). For details, see Annex A.1, Task 1 report.
GADM	Global Administrative Database
GEPCO	Gujranwala Electric Power Company
GHG	Greenhouse Gases
GHI	Global Horizontal Irradiance
GIS	Geographic Information System
GLCNMO	Global Land Cover by National Mapping Organizations
GoP	Government of Pakistan

GW	Gigawatt
ha	Hectare
HESCO	Hyderabad Electric Supply Company
HV	High Voltage (35 to 230 kV)
HVDC	High-Voltage Direct Current
IEA	International Energy Agency
IEC (wind power)	IEC 61400 is an International Standard published by the International Electrotechnical Commission regarding the class/size of wind turbines
IESCO	Faisalabad Electric Supply Company
IFC	International Finance Corporation
IGCEP	Integrated Generation Capacity Expansion Plan
ILR	Inverter Load Ratio, i.e., DC (panel) capacity of a PV plant, compared to its AC (inverter) capacity (also called "DC-to-AC ratio" in the report)
IPP	Independent Power Producer
IRS	Interconnection-Ready Site
IRZ	Interconnection Ready Zones
KE	K-Electric Ltd. (Distribution Company for Karachi)
KM	Kilometers
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt Hour
kWp	Kilowatts Peak
LBNL	Lawrence Berkeley National Laboratory
LCOE	Levelized Cost of Electricity
LEC	Levelized Energy Cost
LESCO	Lahore Electric Supply Company
LULC	Land Use and Land Cover

MapRE	Multi-criteria Analysis for Planning Renewable Energy
MCDA	Multi-criterion decision analysis
MEPCO	Multan Electric Power Company
MV	Medium Voltage
MVA	Megavoltampere
MVAR	Megavoltampere, reactive
MW	Megawatt
MWh	Megawatt hour
MWp	Megawatt Peak
NEPRA	National Electric Power Regulatory Authority
NPCC	National Power Control Center
NPV	Net Present Value (used for economic evaluation of different options here). The NPV for Pakistan (or CPPA as the central power purchasing agency) is calculated against the alternative cost of fossil resources of US$0.1/kWh and a discount rate of 10 percent.[1] Thus, the NPV value represents the economic benefit for Pakistan/CPPA in terms of electricity that is purchased at lower rates compared to fossil-based generation, across the next 25 years.
NREL	National Renewable Energy Laboratory
NTDC	National Transmission & Despatch Company (operator of the transmission grid of Pakistan and employer of this study)
O&M	Operations and Maintenance
PESCO	Peshawar Electric Supply Company
PKR	Pakistani Rupees
POA	Project Opportunity Area
PPA	Power purchase agreement
PPS	Potential Project Site

1 Numbers taken from the Tractebel study performed in parallel to the study at hand, "Variable Renewable Energy Integration and Planning Study, Pakistan," 2019/2020.

PSSE	Power System Simulator for Engineers (software for simulation of the electric grid)
PTI	Power Technology International
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
QESCO	Quetta Electric Supply Company
RE	Renewable Energy
SED	Sindh Energy Department
SEDAC	Socioeconomic Data and Applications Center
SEPCO	Sukkur Electric Power Company
SHS	Solar Home System
SRTM	Shuttle Radar Topographic Mission
SVC	Static VAR Compensator
TSEP	Transmission System Expansion Plan
USD	United States Dollars
UNFCCC	United Nations Framework Convention on Climate Change
Volatility	Volatility here is a measure for how much a generation pattern of a specific technological setup varies across a year (standard deviation of hourly output values as simulated based on available meteorological data from past years). Higher volatility means higher variation in the hourly generation output and therefore tentatively a lower utilization of a given (constant) line capacity and a higher need for reserve power on the national level. Therefore, lower volatilities are desirable from the overall point of view. Daytime volatility refers to the volatility during the times of 8 a.m.–5 p.m., where it matters even more than at night (where total demand is less and available reserves are generally higher).
VRE	Variable Renewable Energy (i.e., solar and wind)
WB	World Bank
WDPA	World Database on Protected Areas
WTG	Wind Turbine Generator

EXECUTIVE SUMMARY

This study was commissioned to shed light on the following critical questions relating to a major expansion of power generation from solar and wind in Pakistan:

1. Considering the government targets for 20 percent of capacity to come from solar and wind by 2025 and 30 percent by 2030, what are the most viable locations and zones for development of solar and wind power plants, taking account of resource potential, physical constraints, environmental and social restrictions, and existing infrastructure?
2. Which are the specific locations suitable for near-term development based on existing substation capacity, and what new locations might need to be developed in the longer term to meet the government targets?
3. Based on the above analysis, what are the likely strategic investments in the electricity transmission system that will be necessary in the near- and long-term to facilitate a major expansion of solar and wind?

The study was carried out by a team of expert consultants over a period of 18 months in collaboration with all the key federal organizations in power system planning, led by the National Transmission & Despatch Company (NTDC) as the primary technical counterpart, with the findings reported to the Ministry of Energy (Power Division). The study utilizes power system data provided primarily by NTDC and was carried out in parallel to a separate study that is summarized in the report "Variable Renewable Energy Integration and Planning Study," published by the World Bank in November 2020 (World Bank 2020). It builds on that study by exploring the optimal locations for solar and wind power development to meet the scale-up of variable renewable energy (VRE) generation recommended in that first study. Detailed consultations were carried out with all federal and provincial organizations throughout the entire process and consisted of two stakeholder workshops and regular technical-level meetings.

The following is a summary of the key findings and conclusions based on the solar and wind resource data; geospatial analyses of physical, environmental, and social constraints; and detailed modeling of the existing load flow at every substation across the country to identify locations where VRE could be easily integrated or might even be beneficial to system stability and efficiency. However, such a summary necessarily misses out on the richness and detail of the work carried out, and interested stakeholders are therefore encouraged to read the full report, and the detailed annexes published separately, to fully understand the results, implications, and recommendations of this study.

Pakistan has ample physical resource potential to reach its targets for VRE to provide 20 percent of total electricity generating capacity by 2025, and 30 percent by 2030.

This study confirms that Pakistan has excellent resources for economically viable solar power and wind power generation, both of which are mostly untapped so far. Especially noteworthy is the huge potential in western Balochistan for both solar and wind power, which will require significant grid infrastructure investments to be exploited. Further excellent areas with large solar potential are to be found in Sindh and southern Punjab, and the wind corridors in southern Sindh around Jhimpir and Gharo still have more potential than what has been developed so far.

The 20 percent VRE target can be largely achieved by utilizing the "low-hanging fruit" of spare capacity at existing substations, thereby avoiding the need for immediate grid upgrades.

By carefully studying the surplus capacity of each substation and transmission line using load flow data, the study concludes that 20 percent of capacity from VRE can be achieved with minimal grid investment by strategically building solar and wind power, in relatively small quantities (20 to 100 MW), close to existing substations and transmission lines. In certain cases the addition of VRE will bring some relief to the local substation or line operating at high or full capacity, and will thus reduce transmission losses—contrary to the commonly held view that VRE integration only imposes costs. This is particularly the case for locations with a high summer daytime load, where the addition of solar power (which has a matching supply profile) can help offset this increased demand.

Achieving the 30 percent VRE target will require some significant new investments, including new high-voltage transmission capacity to access the huge resource potential of Balochistan.

To meet the more ambitious 30 percent target for VRE by 2030, additional transmission lines are needed to connect large-scale solar and wind parks in the gigawatt scale. Among these, the study proposes a high-voltage direct current (HVDC) Chaghi-Muzaffargarh connection between Balochistan and Punjab, which is needed to tap into the large solar and wind resources in western Balochistan. This single project, comprising almost 1,000 km of new HVDC line, would open up around 8 GW of capacity in Balochistan, turning the province into a net energy exporter within the country, thus facilitating its economic development and creating new jobs.

In addition to development of several large-scale "RE hubs," development of VRE should simultaneously happen across the country.

All four provinces have exploitable renewable energy resources, allowing for a wide distribution of economic development benefits and the creation of new jobs in remote parts of the country. Distribution of renewable energy (RE) plants across the whole country also brings the benefits of lower transmission losses due to generation close to load centers, as well as lower overall volatility in the RE generation profile, as shown in the portfolio analysis.

As already noted, **Balochistan** has excellent solar resources and large areas of unused land available. Additionally, Balochistan has the highest wind resource potential of all provinces of Pakistan, with huge potentials, especially in western Balochistan (near Chaghi). The main challenge in Balochistan is the lack of existing grid infrastructure, and therefore major planning efforts and investments will be required to develop the required grid infrastructure needed to tap into the abundant wind resources. This investment will be well spent as the resulting per-unit cost for wind power from western Balochistan will be among the lowest of the whole country.

Khyber Pakhtunkhwa (KPK) has less resources in solar and wind compared to the other provinces. However, there is a limited zone worth exploring for wind power generation, and solar plants of medium size can also be installed with acceptable generation costs. In addition, KPK has large untapped potential for hydropower plants of all scales, leading to the conclusion that a natural focus for this province should be on the development of hydropower, supplemented by VRE where good sites can be identified.

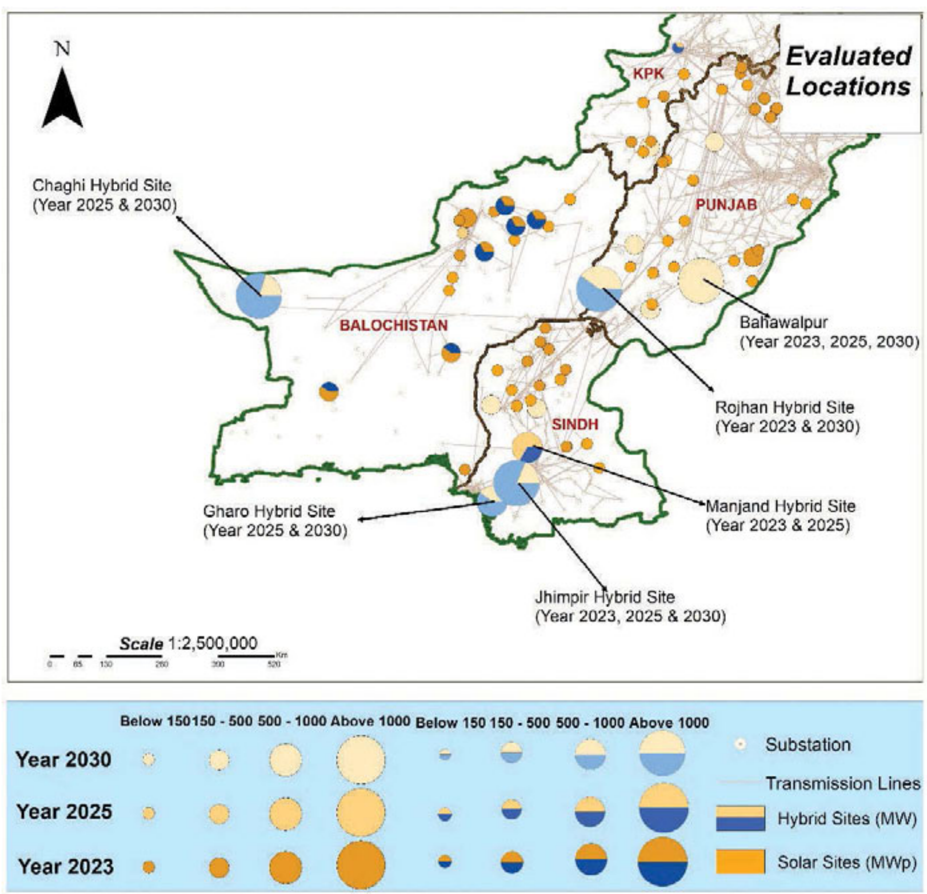
Punjab has very good solar resources and a grid infrastructure which is already well developed. It also has many load centers, so the generated power can be consumed close to its source, reducing losses. A challenge in Punjab is land availability, with development of new solar power plants in competition with agriculture, which is very extensive in central and upper Punjab. However, suitable barren land, which is excellently suited for the development of new solar power plants, is extensively available in southern Punjab. The wind potential in Punjab is minimal.

Sindh has excellent solar resources and two well-known wind corridors (Jhimpir and Gharo). The wind corridors already have some wind farms installed, but there is potential for many more. Sindh also offers large areas with barren land, which are excellently suited for the development of new solar power plants.

Based on the analysis carried out, this study has identified a long list of priority sites and then ranked them to produce an indicative map of where VRE development should optimally occur in order to achieve the most competitive generation from VRE.

The analysis combines extensive data on resource potential, land constraints, and grid infrastructure to identify and rank the most viable sites for VRE generation across Pakistan, the result of which is represented in Figure ES-1.

FIGURE ES-1: PROPOSED PROJECT SITES FOR 2023, 2025, AND 2030



The proposed penetration of VRE in total and for each province derived from this study is summarized in Tables ES-1 and ES-2 respectively, based on the third scenario presented in this report. The analysis proposes 41 potential project sites (PPSs) consisting of 38 photovoltaic (PV) sites and 3 hybrid sites, based on optimal sizing to meet the government target of 30 percent VRE capacity by 2030.

TABLE ES-1: REALISTIC VRE POTENTIAL FOR 2025 AND 2030

	Status Quo		VRE Capacity Additions	
Year	**Unit**	**2019**	**2025**	**2030**
VRE Capacity Share (in MW)	%	4.9%	20.1%	31.5%
Total Installed Generation Capacity	MW	35,130	61,941	75,595
VRE Capacity (Solar + Wind)	MWp	1,735	12,481	23,801

TABLE ES-2: BREAKDOWN OF VRE POTENTIAL IN TECHNOLOGY AND PROVINCES

		VRE Capacity Additions	
Year	**Unit**	**2025**	**2030**
PV	MWp	8,726	13,546
Wind	MW	3,755	10,255
Balochistan	MWp	3,016	10,196
KPK	MWp	280	280
Punjab	MWp	2,420	3,290
Sindh	MWp	6,765	10,035

These numbers have been derived by:

- Applying a top-down approach for the whole country, favoring the most cost-efficient sites;
- Suggesting a ranking for each specific site—while recognizing that final decisions on prioritization of the sites will depend on the Government of Pakistan and the respective provincial governments; and
- Assessing available geographical and grid line data, but no site visits (except for Sindh, where an extension to this study was carried out); this means that more detailed site-specific studies (pre-feasibility studies) are recommended before competitive bidding is carried out for the specified sites.

It is therefore recommended that each province develops their own RE expansion plan based on—but not constrained by—this locational study.

Co-locating solar and wind capacity will help to optimize utilization of the transmission infrastructure, achieving utilization factors of 40–50 percent in some cases and helping to lower costs.

In order to make the best use of the grid infrastructure (both existing and to be built), the co-location of solar and wind power plants is a viable option for a number of locations. By developing solar and wind power generation in the direct vicinity, capacity utilization factors of 40–50 percent for the evacuating grid lines can be achieved, which is exceptionally high for VRE capacity. In this way, grid infrastructure costs are minimized, and the overall fluctuation in the VRE output decreases. In the same way, certain oversizing of solar power plants, as compared to available evacuation capacity, makes economic sense as it achieves better usage of the evacuation lines. Optimization should be done for each location individually. Importantly, the remuneration schemes for Independent Power Producers (IPPs) need to be smartly designed to include stimulus for effective grid capacity utilization (which is normally not within the concern of the IPP). This is something that the Alternate Energy Development Board (AEDB) and the National Electric Power Regulatory Authority (NEPRA) should consider as they put a strategy in place for competitive bidding.

Environmental and social impacts can be largely avoided by screening out used or protected land and by adopting stringent water conservation measures.

As the study is a top-down, Geographic Information System (GIS)-based analysis, environmental and social impact topics were assessed at a general level, but not for each site (except for 10 sites in Sindh analyzed in a separate accompanying annex). The sites proposed in this report have been selected as far as possible to be located on currently unused land (based on satellite images) in order to minimize land usage conflicts and to avoid any necessity for population resettlement. For Balochistan and Sindh, where the lion's share of sites and capacity have been proposed due to the abundant resources in these provinces, this was a relatively easy task, because the best solar and wind resource areas often include vast stretches of barren and unused lands. Therefore, land usage conflicts are rare for the proposed sites. For the specific sites in Sindh which have been visited and analyzed in more detail, no settlements at all were present on the proposed sites.

In terms of environmental impact, the most critical issue is water usage during construction and for cleaning of solar panels during operation. While water consumption of VRE plants is very low compared to thermal power generation or agriculture, increasing water stress should be factored into any site assessment. If water scarcity is especially severe in a certain area, modern ways of cleaning solar panels which are low in water intensity could be proposed as a precondition for new PV plants and as part of the competitive bidding process.

Before the bidding for any specific site is started, a site-specific pre-feasibility study should be commissioned that includes an Environmental and Social Impact Assessment (ESIA). The ESIA should incorporate a stakeholder consultation process with the nearby population that might be affected by increased water usage, or other environmental or social issues. Taking such proactive measures will help avoid future disputes, and will also make the sites more attractive to international developers and/or investors. Opportunities for positive social benefits, such as job creation or the construction of new amenities, should also be considered.

Achieving the VRE capacity targets, and eventually going beyond them, will require major grid investments and operational changes.

In order to accommodate higher shares of solar and wind power in the national electricity mix, Pakistan needs to adopt auxiliary measures that have already been successfully implemented by other countries worldwide. Up to about 2025, solar and wind power plants can easily be integrated into the electric grid as described in this study. For the further planned capacity additions, these auxiliary measures are critical, and their preparation and implementation needs to begin immediately to sufficiently prepare the grid for the future.

The previously published Variable Renewable Energy Integration and Planning Study (World Bank 2020) outlines a series of investments and operational changes that need to be implemented, with many of them required regardless of the addition of more solar and wind power plants to the grid. Additional measures outlined in this report include:

- **Concerted and integrated reinforcement of the electricity grid** to accommodate higher amounts of VRE in the grid. This specifically includes extra high voltage (EHV) links within the country, including the important HVDC connection of western Balochistan to the main grid.
- **Co-locating of solar and wind (hybrid parks)** on the same evacuation line and/or substation to allow for better utilization of grid infrastructure and therefore lower costs; this should be reflected in tenders allowing bidders to propose hybrid solar-wind plants. This is especially relevant for western Balochistan and southern Sindh.
- **Dynamic line rating (DLR),** the real-time measurement and maximum usage of existing grid infrastructure, depending on the actual current temperatures and other operating parameters, should also be implemented.
- **Regional distribution of VRE,** as per the locational planning proposed in this study. Support for net metering and power wheeling would further support local distribution on the medium and low voltage grids.

INTRODUCTION

1. COUNTRY AND SECTORAL CONTEXT

In order to facilitate economic development, the Government of Pakistan began a comprehensive restructuring of the electricity sector in 2013, facilitating access to the electricity market for independent power producers and adopting a multi-billion dollar investment program to expand generation capacity. As a result of these initiatives, new power plants with a total capacity of more than 7,000 MW were put into operation by 2018, of which about 1,700 MW are solar and wind. The total installed generation capacity in the country was 35 GW in 2019 (IGCEP 2019), and as a result of the additional generation capacities, load shedding due to capacity constraints ended in 2019.

While load shedding was eliminated in most areas, line capacity constraints and low electrification rates in rural areas remain as pressing issues. To improve the electrification rate in rural areas, the Government of Pakistan conducted several small hydropower projects in the northern provinces and solar home system (SHS) projects in southern provinces; both of which have only happened sporadically so far and without a real market uptake.

The potential for further renewable energy deployment is immense in Pakistan. The solar resource potential is very high, especially in southern and western parts of the country. The solar photovoltaic potential in southern provinces of Pakistan ranges from 1,400–2,000 kWh/kWp/year (World Bank 2017), which is among the best ranges in the world.

In 2006 the Government of Pakistan adopted a comprehensive Renewable Energy Policy to overcome an electricity shortfall and planned to install small hydropower, wind, and solar power plants (AEDB 2006).

Recent developments and study context

The Government of Pakistan plans to reduce the gap between the further increasing demand and supply of electricity by increasing its generation capacity by another 10 GW by 2022 (IGCEP 2047). In 2018, the government requested the World Bank to support the National Transmission & Despatch Company (NTDC) in analyzing the optimal integration and maximum technically possible level of wind and solar power in the long-term grid expansion plan until 2030. The World Bank study was published in November 2020, although preliminary findings from March 2019 were shared with the government, thereby helping to inform ongoing policy discussions and the preparation of IGCEP 2047.

In March/April 2019, the government released its draft for an updated renewable energy policy with the final report, Alternative and Renewable Energy Policy 2019, published in October 2020 (AEDB 2020). The key announcement by the Ministry of Energy was that 20 percent of the total installed capacity will come from renewable sources by 2025, and 30 percent by 2030. As a preparation for meeting these targets, NTDC requested that the World Bank conduct a "locational study" to identify the most suitable zones and locations for solar and wind power development in the country based on the new targets.

2. STUDY CONTEXT

Solar photovoltaic (PV) and wind power generation are effective and low-cost options to reduce the gap between demand and supply of electricity in all provinces of Pakistan. These renewable energy sources have several advantages compared to conventional electricity generation systems due to their lower generation costs, independence from fossil fuels, and short installation times. By switching conventional electricity generation systems to higher penetrations of renewable energy, Pakistan can get benefits of (1) low operational costs, (2) less importing of fossil fuels, and (3) less adverse effects on climate change, as summarized in the VRE Integration and Planning Study. The Government of Pakistan is taking decisive steps to increase the renewable energy generation all over Pakistan with a large number of locations that have high potential for installation capacity for solar and wind projects at comparatively low costs. However, for a smooth and swift development of renewable energy generation capacities, it is vital to consider land availability and grid integration issues, apart from the analysis of available solar or wind resources only.

For the development of energy infrastructure, strategic spatial planning should be in line with planned grid integration. In the past, new sites for renewable energy sources were often located on the bases of land availability, often resulting in delay in evacuation due to the nonavailability of grid lines. Therefore, availability of grid capacity and minimized distance to existing grid infrastructure are some of the requirements which must be considered when comparing different sites for development of new power plants. Socioeconomic risks, such as resettlements on a specific site, are another factor that needs to be considered. Spatial planning makes projects economically feasible by lowering their costs and enabling rapid growth of renewable energy.

3. STUDY OBJECTIVES AND OUTLINE

The World Bank (WB) is providing a range of support to the Government of Pakistan on sustainable energy under the Pakistan Sustainable Energy Program (P169313), a multiyear, grant-funded technical assistance program. Under this program the WB published a "Variable Renewable Energy Integration and Planning Study" in November 2020 in collaboration with NTDC and other key federal organizations, and in parallel commissioned the present study as a follow-up deliverable.

The objective of this "Variable Renewable Energy Locational Study" is to identify the most suitable zones for solar and wind power development in Pakistan. Furthermore, the study identifies viable sites for potential near-term and longer-term development and provides recommendations on strategic transmission system investments needed to meet the new government targets of at least 30 percent of total generation capacity through new solar and wind power generation capacity by 2030.

The scope of work for this study comprised four tasks, as follows:

1. Assessment of renewable energy zones across Pakistan using a multi-criterion analysis;
2. Grid integration studies for near-term and longer-term development of identified solar and wind zones, including consideration of grid upgrades;
3. Shortlisting and ranking of near-term and longer-term options consistent with meeting government targets on renewable energy, including grid expansion; and

4. Identification of potential near-term sites for solar power generation in Sindh, using the results from Tasks 1–3 combined with more detailed land data, that can be further developed under the Sindh Solar Energy Project.[2]

The Main Report for this study is published separately, and includes four Annexes that provide further details on the four tasks that comprise the scope of work for the study, as follows:

- Annex 1, including background on the mapping layers used for the Task 1 analysis.
- Annex 2, including detailed grid impact studies carried out for all suggested sites proposed under Task 2. These extensive studies have been performed in close collaboration with the NTDC addressing their comments and requirements.
- Annex 3, including more detailed site-specific analysis and surrounding satellite maps for all suggested sites under Task 3.
- Annex 4, which includes detailed analysis for Sindh under Task 4 in support of the Sindh Solar Energy Project.
- Interactive PDFs for solar and wind are also available, showing the different layers and results of Task 1 in high resolution. (No specialized software is required.)

It should be noted that the VRE sites and capacities identified and suggested in this study for the time horizons of 2025 and 2030 have been discussed in detail with the NTDC in order to integrate them into the Integrated Generation Capacity Expansion Plan (IGCEP) 2047 and subsequent IGCEPs, and also the Transmission System Expansion Plan (TSEP) to be developed by the NTDC, which is based on the IGCEP.

[2] https://projects.worldbank.org/en/projects-operations/project-detail/P159712

1. RENEWABLE ENERGY ZONING STUDY FOR PAKISTAN

1.1 APPROACH AND METHODOLOGY FOR RE ZONING ASSESSMENT

In order to allow for strategic planning of new solar and wind plants, countrywide maps have been developed based on solar and wind resources and other factors, both for the country as a whole and for the provinces individually. The result of this GIS-based analysis is therefore mapping for solar and wind, showing the "financial attractiveness" of all possible locations. This "financial attractiveness" takes into account the resource of that particular site (wind speed distribution for wind power and solar irradiation for solar power, obtained from the Global Wind Atlas (DTU 2019), and the Global Solar Atlas, respectively), but also other factors like exclusion of certain protected areas or land-use patterns, as well as the distance to existing road and grid infrastructure. Specifically, a minimum distance to "protected areas" as per the World Database on Protected Areas (WDPA)[3] of 500 meters was used as an inclusion criterion. In the same way, land covers of "forest" and others as per the Global Land Cover[4] were excluded, while "cropland" was not specifically excluded (as it would have removed most areas in Punjab; this land-use conflict will in any case be negotiated by the stakeholders at a later stage). For more details, see the Annex on Task 1.

The financial attractiveness is a relative score based upon the expected price of electricity (US$/kWh) for each POA at which a developer would offer to build a PV or wind plant. It uses a scale of 1–10 with 1 being the least attractive case (highest cost of energy) and 10 the most attractive case (lowest cost of electricity).[5] For details, please refer to the Task 1 and Task 3 Annex reports where the concept is explained in more detail. Here in this report, these attractiveness numbers are made spot-specific and refined.

The maps are shown and explained in this report, and they are available also as interactive documents in the PDF format, where different layers can be switched on and off for analysis.

These maps are of two types: excluding and including the grid connection costs. The maps excluding grid connection costs allow to identify the areas which are generally the most cost-efficient if new grid infrastructure is developed, based on geographic and geophysical conditions only (long-term scenario), while the maps including grid connection costs show the full costs including grid development for new

[3] The World Database on Protected Areas (WDPA) is the most comprehensive global spatial data set on marine and terrestrial protected areas available. The WDPA is a joint project of UNEP and IUCN, produced by UNEP-WCMC and the IUCN World Commission on Protected Areas working with governments and collaborating NGOs.
[4] The Global Land Cover by National Mapping Organizations (GLCNMO) is the data of a 500 meter (15 arc seconds) grid with 20 land cover items. The data were created by using MODIS data observed in 2008 (Terra & Aqua Satellites) with the cooperation of National Mapping Organizations (NMOs) of the world in providing training data and validation. The classification is based on the Land Cover Classification System (LCCS) developed by Food and Drug Organization (FAO).
[5] Alternatively, direct estimated levelized cost of electricity (LCOE) figures could have been used for the mapping, but due to the uncertainties involved, the client preferred to use this unit-free scale in order not to create biases or confusion in the public debate.

projects and allow to identify realistic sites for the near future, based on the existing grid infrastructure (short-term scenario).

Maps for the individual provinces have also been extracted and are provided in Annex A.1. All derived maps and output layers are based on quantitative parameters only and are therefore an objective basis for further discussion. Government decisions on prioritization and development of specific areas and infrastructure are a political process and need to consider other influence factors as well, such as provincial interests compared with federal interests, security issues for remote areas, other infrastructure and energy sector planning, and so on.

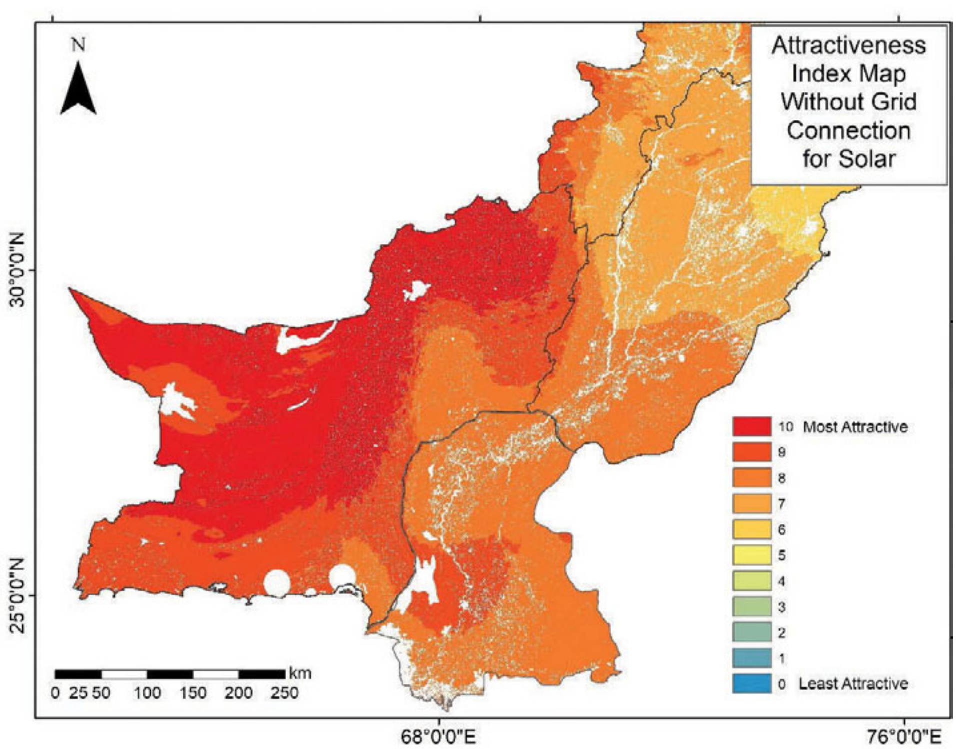
All of these analysis steps have been performed on a GIS basis with detailed data sets for the different parameters as a result. The study uses the latest version of the MapRE tool developed by LBNL and the Geographic Information System (GIS) supported database to identify potentially suitable zones. Further details are given in Annex A.1 for Task 1: Renewable Energy Zoning Study for Pakistan.

1.2 RESULTS OF RENEWABLE ENERGY ZONING STUDY FOR PAKISTAN

1.2.1 Renewable Energy Zoning for Solar PV

Figure 1-1 shows the financial attractiveness level for solar PV technology and the output of MapRE analysis, *excluding* transmission and grid connection costs. This means that here, the financial attractiveness

FIGURE 1-1: SOLAR POWER FINANCIAL ATTRACTIVENESS EXCLUDING TRANSMISSION AND GRID CONNECTION COSTS

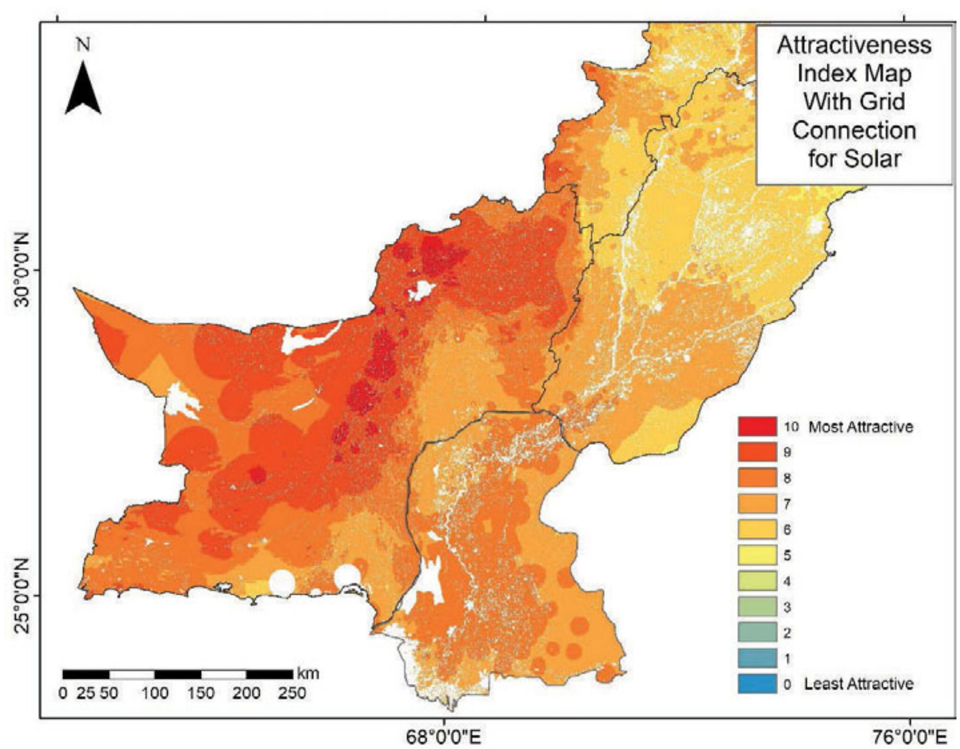


is calculated based purely on the expected output of potential solar plants for this area, irrespective of the distance to any existing grid infrastructure for evacuation of the power. This analysis is relevant for the long-term planning on parks of large-scale (GW): the related long-term grid infrastructure for power evacuation can easily be developed, and it has been found that the per-unit specific cost of grid connection for large-scale parks is very low. In fact, this map shows the specific annual output (determined by irradiation and temperatures) on a different scale as all construction and other costs are kept constant.

It can be seen in the map that conditions for solar power are favorable all over the country, especially in the southern areas of Balochistan, Sindh, and southern Punjab. Northern areas have potential for solar power deployment at a cost which is comparatively higher, but still competitive on the international level. Furthermore, these northern areas have a high potential for hydropower (which was not part of this study).

As a basis for the short-term analysis and opportunity selection, Figure 1-2 illustrates the financial attractiveness for solar power *including* transmission and grid connection costs. By adding the costs for transmission and grid connection, areas close to the existing grid are favored, as these sites can be developed without significant additions to the grid infrastructure. Therefore, this kind of mapping is relevant for near-term future solar plants. In comparison with the former map, it can clearly be seen how areas which are far from the existing grid infrastructure are paying the penalty of additional grid costs (within Balochistan and all the northern areas).

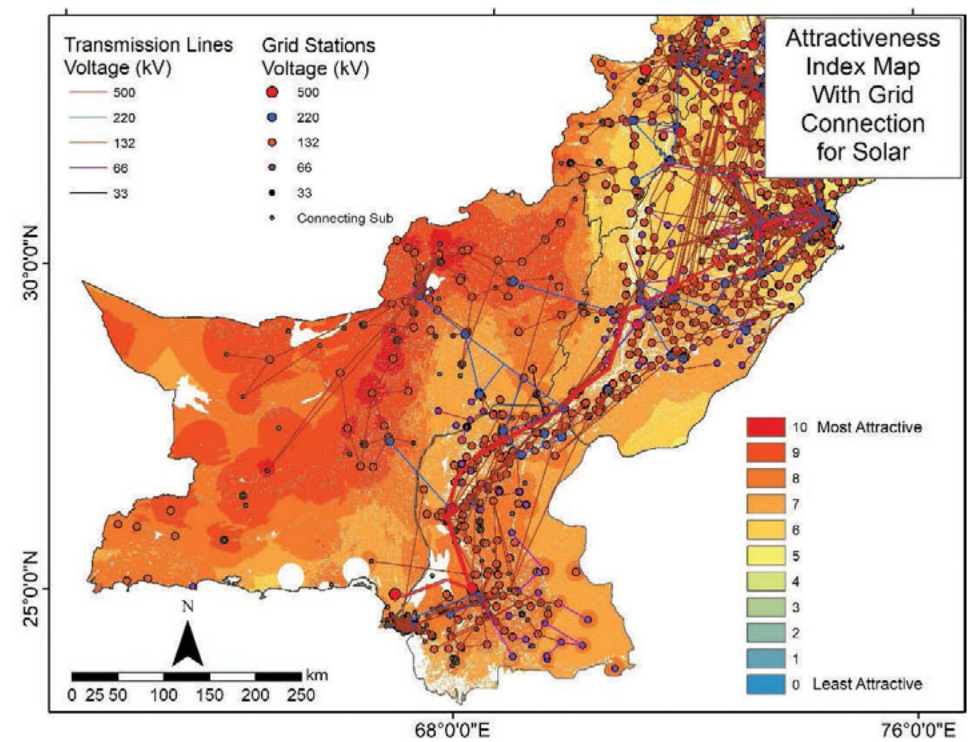
FIGURE 1-2: SOLAR POWER FINANCIAL ATTRACTIVENESS INCLUDING TRANSMISSION AND GRID CONNECTION COSTS



The most suitable areas based on this analysis are located in western Punjab and northeastern Balochistan, near the Afghan border, where good solar resources come together with existing grid infrastructure.

The map in Figure 1-3 shows the financial attractiveness including grid connection, with an overlay of the existing grid infrastructure (transmission lines and grid stations). In this map, the influence of existing infrastructure becomes even more clear. It should also be noted that areas near the existing grid infrastructure are not only more economical to develop, but also can be developed much faster as compared to areas where long grid lines need to be constructed first.

FIGURE 1-3: FINANCIAL ATTRACTIVENESS OF SOLAR POWER, INCLUDING TRANSMISSION AND GRID CONNECTION COSTS AND LOCATION OF EXISTING GRID INFRASTRUCTURE



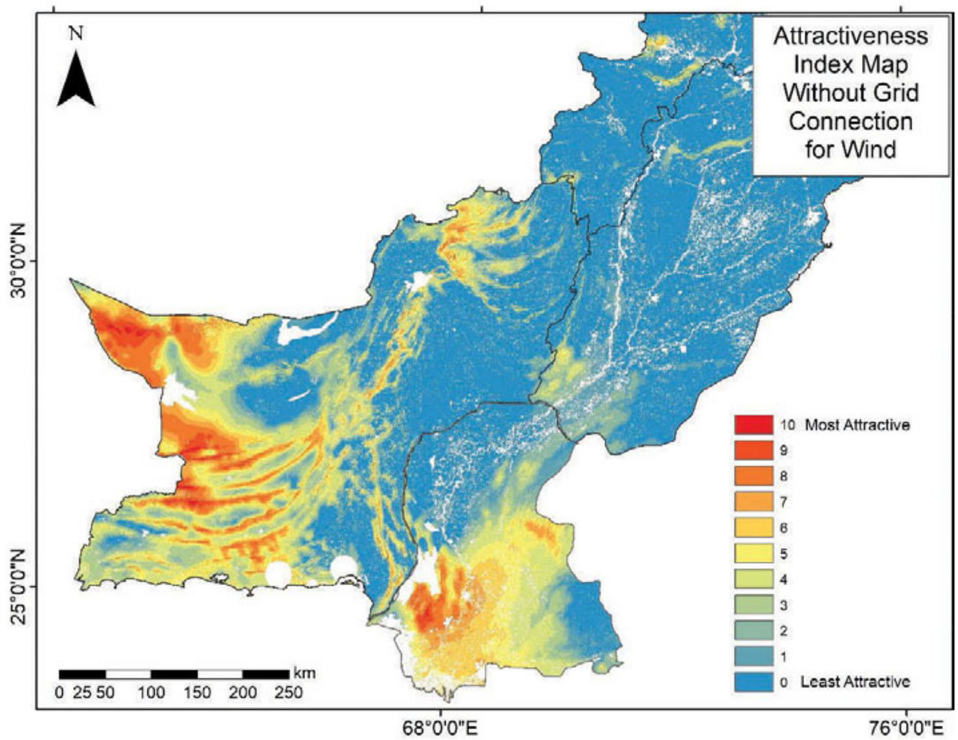
1.2.2 Renewable Energy Zoning for Wind Power

The multi-criteria analysis for wind power potential in Pakistan was carried out based on the capacity factor resource raster data for IEC Class II wind power plants obtained from the Global Wind Atlas. Capacity factor values for wind across the whole of Pakistan range between 13 percent (lowest) and 60 percent (highest).[6] While most areas of Pakistan show low wind speeds and therefore low capacity factors not suitable for wind power plants, there are some areas with considerably higher values that are very favorable for wind power generation.

Figure 1-4 shows the financial attractiveness of wind power generation across Pakistan excluding costs for transmission and grid connection. This is the relevant analysis for the long-term planning of wind

[6] The capacity factor means the total annual energy output of a plant, divided by the amount it would generate at its full (constant) nominal output across the time of a year. For RE technologies, this is a direct measure of the resource availability and therefore site suitability, with 60 percent being excellent sites for wind on the international level.

FIGURE 1-4: FINANCIAL ATTRACTIVENESS OF WIND POWER EXCLUDING TRANSMISSION AND GRID CONNECTION COSTS



parks on a GW scale. Grid infrastructure can be developed in the long run, as the specific cost of grid connection is very low. Overall, it can be seen that the suitable areas for wind are specific pockets rather than widespread areas as for solar, and that these pockets are concentrated in western Balochistan and a corridor in Sindh.

Figure 1-5 shows the financial attractiveness for wind power, including costs for transmission and grid connection. In comparison with the former map, it can be seen that the difference to the former map in this case is much less than for solar power. The areas in western Balochistan are paying a small penalty for being far from existing grid infrastructure, while the wind corridor in Sindh in the central south of Pakistan is almost not affected by the additional costs, as it is close to the existing grid.

This can be seen even more clearly in Figure 1-6 which also displays the grid infrastructure.

This analysis is especially relevant for the short-term opportunity locations as it considers the existing grid infrastructure, and it matches well with already installed wind power projects in the Sindh corridor. The areas in Balochistan have an interesting long-term potential which is not yet developed and needs a major investment into transmission line construction (HVDC). The recommended line goes from Chaghi (western Balochistan) to Muzaffargarh in western Punjab and is needed to tap into this wind power potential in western Balochistan. This line will need several years for planning and construction, so it should be initiated as soon as possible.

FIGURE 1-5: FINANCIAL ATTRACTIVENESS OF WIND POWER INCLUDING TRANSMISSION AND GRID CONNECTION COSTS

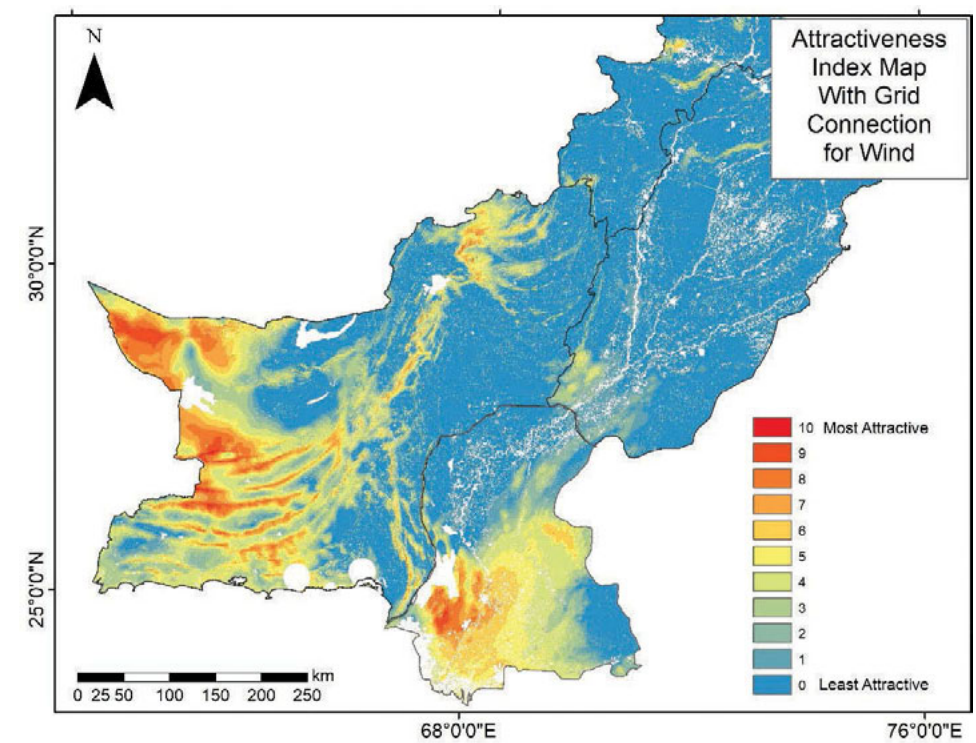
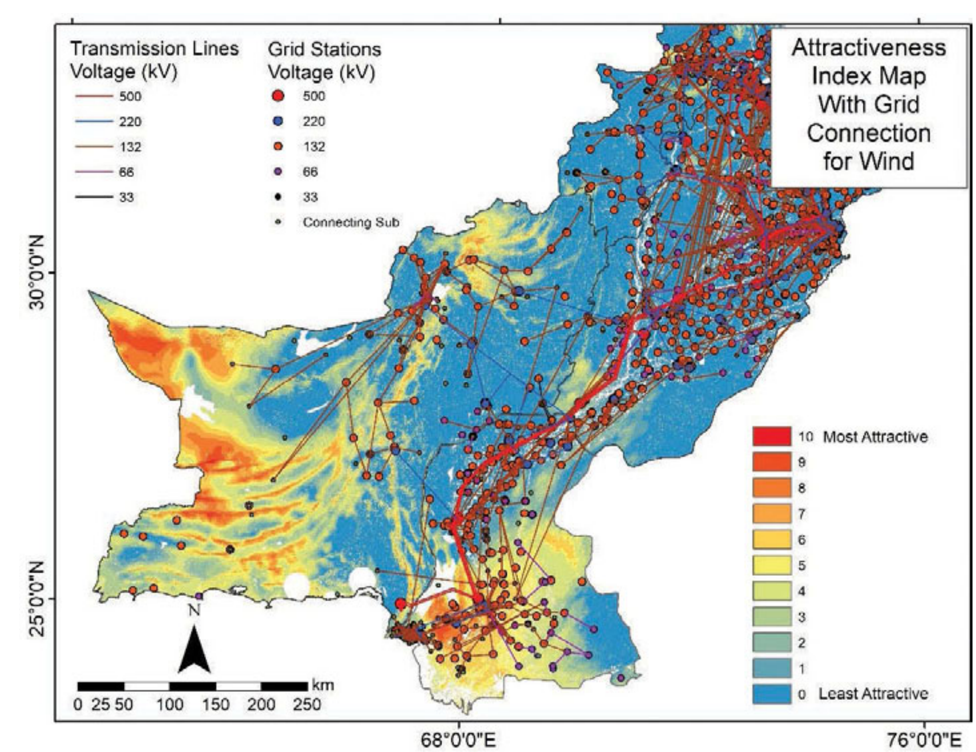


FIGURE 1-6: FINANCIAL ATTRACTIVENESS OF WIND POWER INCLUDING TRANSMISSION AND GRID CONNECTION COSTS AND LOCATION OF EXISTING GRID INFRASTRUCTURE



Short-term opportunities will be determined further based on the result of the grid capacity analysis in Chapter 2.

In Chapter 3, the best sites for wind are analyzed in respect of their possible combination with solar as hybrid power plants, leading to additional benefits.

1.3 CONCLUSION OF RENEWABLE ENERGY ZONING STUDY

Overall, there is a large potential for solar and wind power generation available across Pakistan. At the same time, the distribution varies a lot between the regions.

The average specific production of solar power ranges between about 1,250 and 1,850 kWh/kWp per year with a capacity factor between 16 and 22 percent (for solar installations with fixed inclination), which is very good on the international level. Most areas of Pakistan, except for the northern mountainous regions, have excellent solar potential. Solar potential is slightly higher in Sindh and Balochistan provinces in the South. Northern parts of Balochistan with moderate temperature and good solar irradiance show the highest solar generation potential. There are sites suitable for solar power which are close to the existing grid and can be exploited straightaway (which has already happened during the last years, especially in Punjab), but for the medium and long terms, more grid infrastructure is needed in order to evacuate the power from large-scale solar parks.

The capacity factor for IEC-II type wind power plants[7] in Pakistan ranges between below 15 and up to 60 percent, where 60 percent is an excellent value on the international benchmark. However, these excellent sites for wind power are very concentrated, mostly in the central West of Sindh and in the western part of Balochistan. The central west of Sindh, the Gharo-Jhimpir wind corridor, is already under development.

The northern provinces show scarce wind power potential and limited potential and infrastructure challenges for solar; however, these regions are suitable for hydropower and mini hydropower, and potential is still untapped there. Nevertheless, hydropower was not part of this study due to its very different characteristics and requirements.

The developed output maps in this analysis of Chapter 1 highlight the distribution of the most cost-effective areas for solar and wind generation (indicated by the financial attractiveness as the result parameter) across Pakistan, based on the solar and wind resource potential, applied thresholds, and exclusion criteria on input data layers or constraints. Maps are given in two ways: (1) without the consideration of grid connection costs for the identification of long-term opportunities, and (2) including these grid connection costs for the short-term opportunities. Individual maps have been extracted for each of the provinces for further analysis (see Annex A.1). The maps are also available as high-resolution PDF documents for further analyses.

The high potential areas identified in all of the provinces have considered protected areas and land-use patterns, show high solar or wind resource potential, and are technically and economically feasible for the installation of solar PV and wind plants. These areas can either avail existing transmission grid

[7] The capacity factor means the total annual energy output of a plant, divided by the amount it would generate at its full (constant) nominal output across the time of a year. For RE technologies, this is a direct measure of the resource availability and therefore site suitability.

capacities or they can be developed in the long term with new, large EHV or HVDC grid connection lines which marginalize the cost of grid integration on a cost-per-kWh basis. Specific sites within these high potential areas are analyzed in the following chapters.

The presented analysis is based on resource availability and distance to grid infrastructure. For the actual development of solar and wind power plants, it is crucial to know and analyze the current situation of grid infrastructure. This is provided in Chapter 2.

2. GRID INTEGRATION ANALYSIS FOR POTENTIAL VRE IN PAKISTAN

2.1 INTRODUCTION

The objective of this chapter is firstly to determine the available grid capacities for VRE integration in the attractive renewable energy zones identified in the previous chapter. Secondly, the required grid expansion is determined for three ramp-up scenarios until 2030. These scenarios take the expected future electricity demand growth into consideration and outline recommended grid expansion measures to be implemented in order to cater for the projected VRE generation capacity additions.

2.2 METHODOLOGY

2.2.1 Site Selection Criteria

The grid analysis was conducted for attractive renewable energy zones identified in Chapter 1. Within these zones, specific sites have been identified for detailed grid studies based on the following criteria, in accordance with the results of Chapter 1.

- Wind or solar resource in the area
- Barren or semi-barren lands
- Availability of the electric grid/transmission network in the vicinity
- Transmission network strength
- Local load demand in the vicinity

2.2.2 Study Assumptions

For this study, only the scenarios based on NTDC plans and assumptions have been considered in terms of demand which seems realistic. However, if the demand should develop slower as anticipated during the next years (low-growth scenario), VRE expansion plans can always be revised and reduced accordingly, since VRE has a much shorter planning horizon compared to hydropower or nuclear and VRE planning can be revised from year to year if necessary. So, it is very unlikely that the VRE expansion would overtake the energy demand during the next years.

It must also be noted that NTDC, after detailed consultations with all distribution companies (DISCOs), have prepared their Transmission System Expansion Plan (TSEP) for the year 2025 in which a considerable amount of reinforcements are already planned by NTDC and DISCOs. We have assumed in the study that all those reinforcements will be in place by the time these RE plants will be present in the network.

After incorporating the TSEP of DISCOs and NTDC, further transmission network upgrades have been specified wherever necessary. These upgrades have been segregated into two categories: (i) required for the transmission system of the DISCOs/NTDC in general and (ii) required specifically for the penetration of RE plants. Further additions are always possible but would require significant grid reinforcements. Compared to other grid reinforcement options, the proposed grid extensions were identified as more cost-efficient.

Furthermore, this study was concerned only with utility-scale VRE. In that sense, decentralized VRE, such as solar rooftop plants, would be additional to these numbers and are actually beneficial for the country, both in terms of energy and economy. However, net metering PV plants in Pakistan were at around 40 MWp in total in 2019, and decentralized grid-tied VRE (including captive) is not expected to go beyond 1 GW by 2025, so compared to the utility scale, these numbers are rather small. And again, here the same applies as mentioned above—if decentralized generation develops much faster than anticipated, the targets for utility scale VRE could be revisited any time if necessary.

2.2.3 VRE Sizing and Planning Criteria

The installed capacity of a solar power plant is assumed as the capacity of direct current (DC) PV panels installed in the solar plant. The alternating current (AC) output at the point of interconnection with the grid, after the converter losses and collector-system losses, has been assumed at 85 percent of the installed DC, at peak hours of irradiation (midday), i.e., 85 MW AC against 100 MWp DC (Scenario 1). However, for Scenario 2, with higher DC installed capacity to improve the capacity factor (CF), the maximum AC offtake remains 85 MW from the perspective of grid capacity. Therefore, additional energy yield would be achieved through enhancing the MW outputs in the morning and afternoon hours. All the capacities MWp mentioned in this report are the DC installed capacities.

The installed capacity of wind power plants is assumed as the total of the output of wind turbine generators (WTGs) installed in the plant. The offtake at point of interconnection with the grid, after wake losses and other plant losses have been assumed is 95 percent of the installed capacity as per nominal rated output of WTGs.

For hybrid wind/solar power plants, the coincident maximum offtake from the plant has been assumed equal to the offtake under maximum wind condition and minimum solar output.

Planning criteria are assumed as follows:

Voltage	± 5%, normal operating condition
	± 10%, contingency conditions
Frequency	50 Hz nominal
	49.8 Hz to 50.2 Hz variation in steady state
	49.4–50.5 Hz, min/max contingency frequency band

2.2.4 Spot Years and Cases for Study

The spot years of study have been selected keeping in view the governmental targets of renewables of 20 percent by 2025 and 30 percent by 2030 of the installed generation capacity in Pakistan's interconnected grid. The spot years of study as agreed with the NTDC are:

- Spot Year 1: 2023 (short-term scenario)
- Spot Year 2: 2025 (medium-term scenario)
- Spot Year 3: 2030 (long-term scenario)

The sequencing of adding VRE plants has been prioritized such that initially the plants requiring minimum reinforcements on the grid should come in 2023, those with relatively more investment in 2025, and those with higher investment in 2030.

The following cases have been simulated and studied as proposed by the Power System Planning Department of the NTDC:[8]

Summer:

1. Day peak (with full solar and wind output)
2. Evening peak (no solar and full wind output)
3. Night: 85 percent of day peak (no solar and 80 percent wind output)

Winter (60 percent of summer peak):

1. Day peak (with 70 percent solar and 15 percent wind output)
2. Evening peak (no solar and 20 percent wind output)
3. Night: 63 percent of day peak (no solar and 20 percent wind output)

2.2.5 Technical Grid Studies

System analysis has been performed for the selected spot years of study, and includes:

- Load flow calculations to analyze:
  - Spare capacity in transmission lines of 132 kV, 220 kV, and 500 kV
  - Substation capacities of 500/220 kV, 220/132 kV, and 132/11 kV
- Short circuit calculations and equipment fault rating in the vicinity of proposed locations
- Dynamic Grid Integration Simulation at the identified location

The detailed analysis of the abovementioned studies along with the results are provided in Annex A.2 for Task 2: Grid Integration Analysis for Potential VRE in Pakistan.

2.3 EXISTING AND PLANNED VRE PLANTS

Existing and planned VRE plants have been included in the base case for the Technical Grid Studies. As of October 2020, the installed capacities of VRE plants in the system (including K-Electric,[9] or KE), were:

- Existing solar plants = 500 MW
- Existing wind power plants = 1,235 MW

[8] The NTDC has taken the historical data from the past few years and calculated the loading ratios between summer and winter seasons. Similarly, they have calculated the ratios between day, evening, and night times and provided these loading ratios for simulation purposes, considering that they are using the same numbers for their day-to-day simulation work.
[9] K-Electric is the private company that owns and operates the electricity grid in and around the city of Karachi, in Sindh.

In addition, planned VRE projects have been included based on the information provided by NTDC, KE, and AEDB. The planned VRE plant capacities until the year 2025 are:

- Planned solar plants = 690 MW
- Planned wind power plants = 1,010 MW

The results of technical grid studies for each province for each spot year are provided below.

2.4 TECHNICAL GRID STUDIES: SINDH PROVINCE

Technical grid studies, including load flow for normal and contingency conditions, short circuit analysis and dynamic stability analysis, have been carried out for the identified sites/zones selected on the basis of abovementioned criteria in Sindh Province.

2.4.1 Spot Year 1: 2023 (short-term scenario)

The sites in Table 2-1 for solar and wind power plants have been studied and found technically feasible for grid integration in Sindh Province for the short-term scenario of 2023.

Reinforcement required by the year 2023

All the power plants mentioned in Table 2-1 can be interconnected at the 132 kV level with the existing and planned network without any further reinforcement in the 132 kV network.

However, to evacuate the power from southern power plants within the NTDC network and the proposed VRE plants in Sindh (especially plants south of Jamshoro), it is proposed that the following 500 kV circuit lines must be in place by the year 2023:

- 500 kV double circuit transmission line between Matiari to Moro
- 500 kV double circuit transmission line between Moro to Rahim Yar Khan

TABLE 2-1: SITES FOR SHORT-TERM SCENARIO SINDH

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Nara	SEPCO	Solar	50
2	Manjhand (Jamshoro)	HESCO	Solar	50
3	Jacobabad	SEPCO	Solar	100
4	Jamaro (Sanghar)	HESCO	Solar	100
5	Sukkur	SEPCO	Solar	100
6	Rato Dero	SEPCO	Solar	100
7	Shikarpur	SEPCO	Solar	100
8	Mehrabpur	SEPCO	Solar	100
9	Jhimpir	HESCO/NTDC	Wind	480
	Total Addition by 2023			**1,180 MW**

2.4.2 Spot Year 2: 2025 (medium-term scenario)

The sites in Table 2-2 for solar and wind power plants have been studied and found technically feasible for grid integration in the Sindh Province for the medium-term scenario of 2025.

TABLE 2-2: SITES FOR MEDIUM-TERM SCENARIO SINDH

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Moro	SEPCO	Solar	50
2	Patt	SEPCO	Solar	100
3	Khipro	HESCO	Solar	100
4	Umerkot	HESCO	Solar	100
5	Rohri	SEPCO	Solar	100
6	Padidan	SEPCO	Solar	100
7	Warah	SEPCO	Solar	100
8	Manjhand (Jamshoro)	HESCO/NTDC	Wind/Solar Hybrid	350 MW Solar 200 MW Wind
9	Jhimpir	HESCO/NTDC	Wind/Solar Hybrid	500 MW Wind 250 MW Solar
10	Gharo	K-Electric	Wind/solar Hybrid	200 MW Wind 100 MW Solar
		Total Addition between 2023 and 2025		**2,250 MW**

Reinforcement required by the year 2025

After incorporating the plans by the year 2025, most of the power can be evacuated; however, some reinforcements will be required for the evacuation of power from the plants in Table 2-2, as well as for the enhancement of the grid capacities.

Following is the list of reinforcement required by the year 2025:

For system

- Re-conductoring of the 30 km long 132 kV double circuit line between FFC and TGF wind plants to the Nooriabad grid station of HESCO from the Lynx to Greeley conductor.

For VRE plants

- Stringing of the second 132 kV circuit between Naushero Feroz to Padidan grid stations (length = 25 km, conductor = Lynx) for the reliable power evacuation of the **Padidan Solar Site.**
- Stringing of the second 132 kV circuit between Naseerabad to Warah grid stations (length = 25 km, conductor = Lynx) for the reliable power evacuation of the **Warah Solar Site.**

- Stringing of the second 132 kV circuit between Umerkot to Chor grid stations (length = 20 km, conductor = Lynx) and between Samaro and Umerkot grid stations (length = 36 km, conductor = Lynx) for the reliable power evacuation of the **Umerkot Solar Site.**
- Extension at 220 kV switchyard of 500/220 kV Jamshoro grid station of NTDC will be required for the interconnection of the **Manjhand Wind/Solar Hybrid Site.**
- Re-conductoring of the 30 km long 132 kV single circuit line between Sehwan to Dadu New from the Lynx to Greeley conductor for the **Manjhand Solar Site.**
- Up-gradation of the Jhimpir grid station from 220 kV to the 500 kV level by addition of two 500/220 kV transformers of 500 MVA each for the evacuation of wind/solar hybrid power plants from the **Jhimpir wind** corridor.

2.4.3 Spot Year 3: 2030 (long-term scenario)

The sites in Table 2-3 for solar and wind power plants have been studied and found technically feasible for grid integration in the Sindh Province for the long-term scenario of 2030.

Reinforcement required by the year 2030

As the transmission plan beyond 2025 is not available, some assumptions have been made, as agreed with the NTDC, to accommodate the increasing load in Sindh Province along with the evacuation of power from the power plants mentioned in Table 2-3.

For system

- Conversion of the Moro 500 kV switching station to 500/220/132 kV substation by adding two 500/220 kV transformers each of 750 MVA, and two 220/132 kV transformers each of 250 MVA.
- Upgrade of the Nawabshah 132 kV grid station to 220 kV by adding two 220/132 kV transformers of 250 MVA each.
- A 220 kV double circuit transmission line of 65 km from Moro to Nawabshah.

For VRE plants

- Addition of third 500/220 kV transformer of 500 MVA at the Jhimpir grid station for evacuation of power from **Jhimpir Wind/Solar Hybrid Site.**

TABLE 2-3: SITES FOR LONG-TERM SCENARIO SINDH

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Wahi Pandhi (Dadu)	SEPCO/NTDC	Solar	300
2	Nawabshah	HESCO/NTDC	Solar	400
3	Jhimpir	HESCO/NTDC	Wind/Solar Hybrid	500 MW Wind 250 MW Solar
		Total Addition between 2025 and 2030		**1,450 MW**

2.5 TECHNICAL GRID STUDIES: BALOCHISTAN PROVINCE

Technical grid studies including load flow for normal and contingency conditions, short circuit analysis, and dynamic stability have been carried out for the identified sites/zones selected on the basis of above-mentioned criteria in Balochistan Province.

2.5.1 Spot Year 1: 2023 (short-term scenario)

The sites in Table 2-4 for solar and wind power plants have been studied and found technically feasible for grid integration in the Balochistan Province for the short-term scenario of 2023.

TABLE 2-4: SITES FOR SHORT-TERM SCENARIO BALOCHISTAN

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Mach	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
2	Panjgur	QESCO	Wind/Solar Hybrid	200 MW Wind 100 MW Solar
3	Khuzdar	QESCO	Wind/Solar Hybrid	200 MW Wind 100 MW Solar
4	Chinali, Qila Saifullah	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
5	Darzanda, Qila Saifullah	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
6	Muslim Bagh	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
7	Khanozai	QESCO	Solar	100
8	Mastung	QESCO	Solar	100
9	Bostan, Quetta	QESCO	Solar	100
10	Kuchlak, Pishin	QESCO	Solar	200
11	Hub	K-Electric	Solar	150
		Total Addition by 2023		**1,850 MW**

Reinforcement required by the year 2023

For system

To enhance the reliability of system it is proposed that:

- The 132-kV single circuit transmission line between Yaru and Huramzai proposed for 2024 by QESCO should be constructed by the year 2023.

The impact of all these power plants have been checked on the 500-kV network of NTDC as well. The plants proposed in Sindh and Balochistan, along with thermal plants in the South, will cause congestion on the 500 kV transmission lines. Therefore, it is recommended that the following transmission lines must be in place before the commissioning of these plants:

- 500 kV double circuit transmission line between Matiari to Moro
- 500 kV double circuit transmission line between Moro to Rahim Yar Khan

For VRE plants

All the power plants mentioned can be integrated in the network of QESCO and KE without any major reinforcement in the network considering all the planned reinforcement by QESCO will be in place by the year 2023.

2.5.2 Spot Year 2: 2025 (medium-term scenario)

The sites in Table 2-5 for solar and wind power plants have been studied and found technically feasible for grid integration in the Balochistan Province for the medium-term scenario of 2025.

Reinforcement required by the year 2025

For VRE plants

While considering the expansion plans for infrastructure of QESCO by the year 2025, all of the above proposed plants can be integrated without any additional reinforcement. However, to accommodate for the Chaghi Wind/Solar Hybrid Site (Phase-1), the following reinforcement is proposed:

- A double circuit of 220 kV from Chaghi to Mastung 220 kV grid station with an intermediate switching station at Kharan. The length of the line is approximately 500 km, and the conductor to be used will be Quad Bundled Rail. A switched shunt capacitor bank of 100 MVAR is also proposed at the Kharan switching station.

TABLE 2-5: SITES FOR MEDIUM-TERM SCENARIO BALOCHISTAN

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Loralai	QESCO	Solar	50
2	Musafirpur	QESCO	Solar	50
3	Kalat	QESCO	Solar	100
4	Mangochar	QESCO	Solar	100
5	Hernai	QESCO	Solar	100
6	Chaghi Phase-1	QESCO/NTDC	Wind/Solar Hybrid	500 MW Wind 250 MW Solar
		Total Addition between 2023 and 2025		**1,150 MW**

2.5.3 Spot Year 3: 2030 (long-term scenario)

The sites in Table 2-6 for solar and wind power plants have been studied and found technically feasible for grid integration in the Balochistan Province for the long-term scenario of 2030.

TABLE 2-6: SITES FOR LONG-TERM SCENARIO BALOCHISTAN

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Quetta	QESCO	Solar	150
2	Chaghi (Phase-2)	NTDC	Wind/Solar Hybrid	4,000 MW Wind
				20,050 MW Solar
		Total Addition between 2025 and 2030		**6,150 MW**

Reinforcement required by the year 2030

Chaghi has a lot of potential for both wind and solar power plants, but it is far away from the load centers. It is proposed that the HVDC line between Chaghi and the load center should be built for a higher capacity of about 6 GW (Phase-2). The initial evacuation of power would be about 4 GW (taking the coincidence factor of wind and solar) by the year 2030. After 2030, further expansion can be done at the Chaghi Site, considering the very high wind and solar potential at this site.

To evacuate the power from the new 6 GW wind/solar hybrid park, the following transmission reinforcements are required:

- ±800 kV HVDC convertor station at Chaghi of 4 GW (can be upgraded to 6 GW later on) with a 500 kV HVAC substation for collection system
- ±800 kV HVDC convertor station at Muzaffargarh of 4 GW (can be upgraded to 6 GW later on) with a 500 kV HVAC substation for dispersal of power to load centers
- ±800 kV HVDC transmission line of approximately 1,000 km having 6 GW capacity between Chaghi and Muzaffargarh convertor stations.
- Looping in/out of 500 kV single circuit between DG Khan and Muzaffargarh at Muzaffargarh convertor station
- Looping in/out of 500 kV single circuit between Guddu and Muzaffargarh at Muzaffargarh convertor station
- Looping in/out of 500 kV single circuit between Guddu-New and Muzaffargarh at Muzaffargarh convertor station
- Looping in/out of 500 kV single circuit between Rahim Yar Khan and Multan at Muzaffargarh convertor station
- Addition of two 500/220 kV transformers at Muzaffargarh convertor station each of 750 MVA
- A 65 km long double circuit of 220 kV from Muzaffargarh convertor station to Nagshah grid station
- Interconnection of Chaghi hybrid plant with proposed Chaghi Phase-1 plant at 220 kV level via a 50 km long quad bundled transmission line

The proposed HVDC line is of 6 GW (initially operated for 4 GW), ±800 kV bipole HVDC line connecting Chaghi in western Balochistan to Muzaffargarh in western Punjab, bringing power from very suitable hybrid locations for wind and solar in those remote areas to the load centers in eastern Balochistan and western Punjab. This makes sense because the wind and solar conditions around Chaghi allow very low-cost power generation, and the hybrid plant setup allows a good plant factor of an average of around 50 percent (i.e., equal to a large size hydropower plant) justifying good utilization of the interconnection line. The line costs of the HVDC line, including stations and the related reinforcements of HVAC lines, are estimated at US$1,435 million, which is extrapolated with reference to the actual cost of the Matiari-Lahore ±660 kV HVDC line. At an annual power transportation of 22,700 GWh and an estimated lifetime of 50 years, this leads to a per-unit transportation cost of around US$0.13 kWh, which is very reasonable.

HVDC lines are specifically built in order to transport electricity across long distances while minimizing the losses. Losses are estimated at 2.5 to 3.0 percent across the 1,000 km.

2.6 TECHNICAL GRID STUDIES: PUNJAB PROVINCE

Technical grid studies, including load flow for normal and contingency conditions, short circuit analysis, and dynamic stability analysis, have been carried out for the identified sites/zones selected on the basis of abovementioned criteria in Punjab Province.

2.6.1 Spot Year 1: 2023 (short-term scenario)

The sites in Table 2-7 for solar and wind power plants have been studied and found technically feasible for grid integration in Punjab Province for the short-term scenario of 2023.

TABLE 2-7: SITES FOR SHORT-TERM SCENARIO PUNJAB

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	QA Solar Park	MEPCO/NTDC	Solar	500
2	Chishtian	MEPCO/NTDC	Solar	300
3	Dina	IESCO	Solar	100
4	Fateh Jang	IESCO	Solar	100
5	Ahmadal	IESCO	Solar	50
6	Noorsar	MEPCO	Solar	30
7	Kharian	GEPCO		50
8	Taunsa	MEPCO	Solar	50
9	Dinga	GEPCO	Solar	50
10	Rojhan (Phase-1)	MEPCO	Wind/Solar Hybrid	200 MW Wind 100 MW Solar
		Total Addition by 2023		**1,510 MW**

Reinforcement required by the year 2023

For system

Technical grid analysis reveals that the following reinforcements are required in the network of MEPCO even without the power plants mentioned in Table 2-7:

- Re-conductoring of Muzaffargarh to Khan Garh 19 km long 132 kV single circuit transmission line to rail conductor
- Re-conductoring of Muzaffargarh to Muzaffargarh-New 3 km long 132 kV double circuit transmission line to rail conductor

For VRE plants

The following reinforcements/operational measures are required in the network of MEPCO for the evacuation of above-mentioned power plants:

- Lal Suhanra to Karor Pacca 132 kV single circuit proposed in the year 2025 should be completed by the year 2023.
- A 132-kV double circuit 45 km long on rail conductor between Vehari-New to Burewala grid stations.
- Line opening between Bahawalpur and Lodhran 132 kV grid stations during daytime.
- Line opening between Noorsar and Bahawal Nagar 132 kV grid stations during daytime.

2.6.2 Spot Year 2: 2025 (medium-term scenario)

The sites in Table 2-8 for solar power plants have been studied and found technically feasible for grid integration in Punjab Province for the medium-term scenario of 2025.

Reinforcement required by the year 2025

For VRE plants

As per technical grid studies the following reinforcements/operational measures are required for the evacuation of power plants mentioned in Table 2-8:

- Addition of one 220/132 kV transformer of 250 MVA at the Lal Suhanra 220/132 kV grid station for addition at **QA Solar Power Site.**
- Line opening between Noorsar and Bahawal Nagar 132 kV grid stations during daytime.
- Line opening between Hasilpur and Chistian 132 kV grid stations during daytime.

TABLE 2-8: SITES FOR MEDIUM-TERM SCENARIO PUNJAB

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Chakri	IESCO	Solar	100
2	Kalar Kahar	IESCO	Solar	100
3	Chunian	LESCO	Solar	30
4	Habibabad	LESCO	Solar	30
5	Darya Khan	FESCO	Solar	100
6	Athran Hazari	FESCO	Solar	100
7	Rangpur	MEPCO	Solar	50
8	Muzaffargarh	MEPCO	Solar	100
9	Ali pur	MEPCO	Solar	100
10	Pindi Gheb	IESCO	Solar	100
11	Hasilpur	MEPCO	Solar	100
12	Fort Abbas	MEPCO	Solar	50
13	Lodhran	MEPCO	Solar	30
14	Firoza	MEPCO	Solar	50
15	Dajal	MEPCO	Solar	50
16	QA Solar (Phase-2)	MEPCO/NTDC	Solar	300
	Total Addition between 2023 and 2025			**1,390 MW**

2.6.3 Spot Year 3: 2030 (long-term scenario)

The sites in Table 2-9 for solar and wind power plants have been studied and found technically feasible for grid integration in Punjab Province for the long-term scenario of 2030.

TABLE 2-9: SITES FOR LONG-TERM SCENARIO PUNJAB

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Rahim Yar Khan	MEPCO/NTDC	Solar	50
2	Dera Ghazi Khan	MEPCO/NTDC	Solar	50
3	Jauharabad	FESCO/NTDC	Solar	100
4	Rojhan (Phase-2)	NTDC	Wind/Solar Hybrid	500 MW Wind 250 MW Solar
	Total Addition between 2025 and 2030			**2,300 MW**

Reinforcement required by the year 2030

For VRE plants

The following reinforcements are required for the evacuation of power plants mentioned in Table 2-9:

- Addition of third 220/132 kV transformer of 250 MVA at Dera Ghazi Khan grid station.
- Addition of third 220/132 kV transformer of 250 MVA at Jauharabad grid station.

2.7 TECHNICAL GRID STUDIES: KHYBER PAKHTUNKHWA PROVINCE

Technical grid studies, including load flow for normal and contingency conditions, short circuit analysis, and dynamic stability analysis, have been carried out for the identified sites/zones selected on the basis of abovementioned criteria in Khyber Pakhtunkhwa (KPK) Province.

2.7.1 Spot Year 1: 2023 (short-term scenario)

The sites in Table 2-10 for solar power plants have been studied and found technically feasible for grid integration in KPK Province for the short-term scenario of 2023.

TABLE 2-10: SITES FOR SHORT-TERM SCENARIO KPK

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Karak	PESCO	Solar	50
2	Pezu	PESCO	Solar	100
3	Tank	PESCO	Solar	50
		Total Addition by 2023		**200 MW**

Reinforcement required by the year 2023

Technical grid analysis reveals that the power plants mentioned in Table 2-10 can be evacuated without any reinforcement in the system.

2.7.2 Spot Year 2: 2025 (medium-term scenario)

The sites in Table 2-11 for solar and wind power plants have been studied and found technically feasible for grid integration in KPK Province for the medium-term scenario of 2025.

TABLE 2-11: SITES FOR MEDIUM-TERM SCENARIO KPK

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Bannu	PESCO	Solar	100
2	Kohat	PESCO	Solar	100
3	Kolachi	PESCO	Solar	100
4	Warsak	PESCO	Wind/Solar Hybrid	50 MW Wind 25 MW Solar
		Total Addition between 2023 and 2025		**375 MW**

Reinforcement required by the year 2025

Technical grid analysis reveals that the power plants in Table 2-11 can be evacuated without any reinforcement in the system.

2.7.3 Spot Year 3: 2030 (long-term scenario)

The site in Table 2-12 for a solar power plant has been studied and found technically feasible for grid integration in KPK Province for the long-term scenario of 2030.

TABLE 2-12: SITES FOR LONG-TERM SCENARIO KPK

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Dera Ismail Khan	PESCO/NTDC	Solar	400
		Total Addition between 2025 and 2030		**400 MW**

Reinforcement required by the year 2030

Technical grid analysis reveals that the power plant mentioned in Table 2-12 can be evacuated without any reinforcement in the system.

2.8 INTERCONNECTION-READY SITES

Interconnection-Ready Sites (IRSs) have been identified as those locations which do not require any grid reinforcement for the additional feed-in from new power plants. These sites can therefore be implemented immediately (with the given sizes) without causing any congestion or overloading in the network.[10] These sites are listed in Table 2-13.

[10] The wind power plants proposed in Jhimpir corridor by the year 2023 shall have the grid available for their evacuation by that time. However, considering the congestion on the 500 kV southern network of NTDC, reinforcements of 500 kV network are required. Therefore, this site has not been included in the IRSs list.

TABLE 2-13: LIST OF INTERCONNECTION-READY SITES

Serial Number	Location	Concerned DISCO	Type	Size (MW)
1	Nara	SEPCO	Solar	50
2	Manjhand (Jamshoro)	HESCO	Solar	50
3	Jacobabad	SEPCO	Solar	100
4	Jamaro (Sanghar)	HESCO	Solar	100
5	Sukkur	SEPCO	Solar	100
6	Shikarpur	SEPCO	Solar	100
7	Mehrabpur	SEPCO	Solar	100
8	QA Solar Park	MEPCO/NTDC	Solar	500
9	Chistian	MEPCO/NTDC	Solar	300
10	Dina	IESCO	Solar	100
11	Fateh Jang	IESCO	Solar	100
12	Ahmadal	IESCO	Solar	50
13	Noorsar	MEPCO	Solar	30
14	Kharian	GEPCO	Solar	50
15	Taunsa	MEPCO	Solar	50
16	Dinga	GEPCO	Solar	30
17	Rojhan	MEPCO	Wind/Solar Hybrid	200 MW wind 100 MW solar
18	Karak	PESCO	Solar	50
19	Pezu	PESCO	Solar	100
20	Bostan, Quetta	QESCO	Solar	100
21	Kuchlak, Pishin	QESCO	Solar	200
22	Panjgur	QESCO	Wind/Solar Hybrid	200 MW Wind 100 MW Solar
23	Khuzdar	QESCO	Wind/Solar Hybrid	200 MW Wind 100 MW Solar
24	Chinali, Qila Saifullah	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
25	Darzanda, Qila Saifullah	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
26	Muslim Bagh	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar

(continues)

TABLE 2-13: *CONTINUED*

Serial Number	Location	Concerned DISCO	Type	Size (MW)
27	Mach	QESCO	Wind/Solar Hybrid	100 MW Wind 50 MW Solar
28	Khanozai	QESCO	Solar	100
29	Hub	K-Electric	Solar	150
		Total		**4,160 MW**

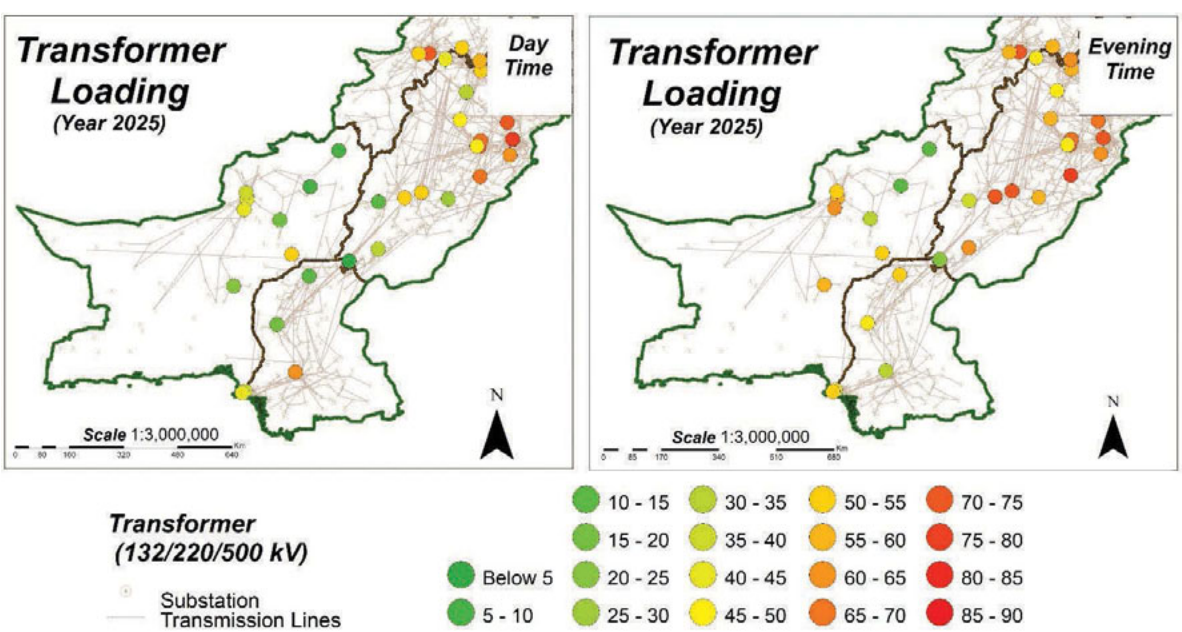
2.9 TRANSMISSION LOSSES

Technical grid studies have also analyzed the impact of VRE plants on the transmission and transformation losses of the grid. Most of the country's generation is installed at 500 kV or 220 kV network of NTDC, i.e., hydel generation in the North and thermal generation in the mid-country and South. All this power flows from 500/220 kV and 220/132 kV transformers to the 132-kV network of DISCOs.

Most of the VRE power plants proposed in this study are proposed to be installed at the 132 kV level of DISCOs, especially in the short- and medium-term scenarios. These VRE power plants at the 132 kV levels feed the load locally. Solar power plants have been spread out across the country; thus at daytime when solar power plants are feeding the local loads, the loading of 500/220 kV and 220/132 kV transformers reduce significantly.

The map in Figure 2-1 reflects the reduction in transmission losses, especially during the daytime, by injecting regionally produced distributed VRE.

FIGURE 2-1: PERCENTAGE LOADING OF 500/220 KV AND 220/132 KV TRANSFORMERS



2.9.1 Case Studies

The reduction of loading of transmission lines during the daytime is illustrated by the following two examples.

2.9.1.1 Case study 1

The first example is of two proposed solar power plants in Sindh, namely Moro Solar Power Plant and Padidan Solar Power Plant. Both plants are connected to the same 132 kV transmission line. The complete area of Moro, New Jatoi, Naushero Feroz, and Padidan is being fed from the Dadu 500/220/132 kV grid station.

During the daytime, the solar power plants feed the local load, and the electric load on the main 132 kV line from Dadu is significantly lowered. At daytime, the loading of the line from Dadu to Moro is only 14 percent (see Figure 2-2), while the same transmission line reaches the loading of 51 percent during evening time when the output from solar plants is zero (see Figure C-3). As per the loading of the line, the line loss during the daytime at the Dadu to Moro line is 0.13 MW because of the local source of power available during the daytime, whereas it increases at evening time to a value of 0.82 MW when local solar generation is off.

FIGURE 2-2: TRANSMISSION LINE LOADING FROM DADU (DAYTIME)

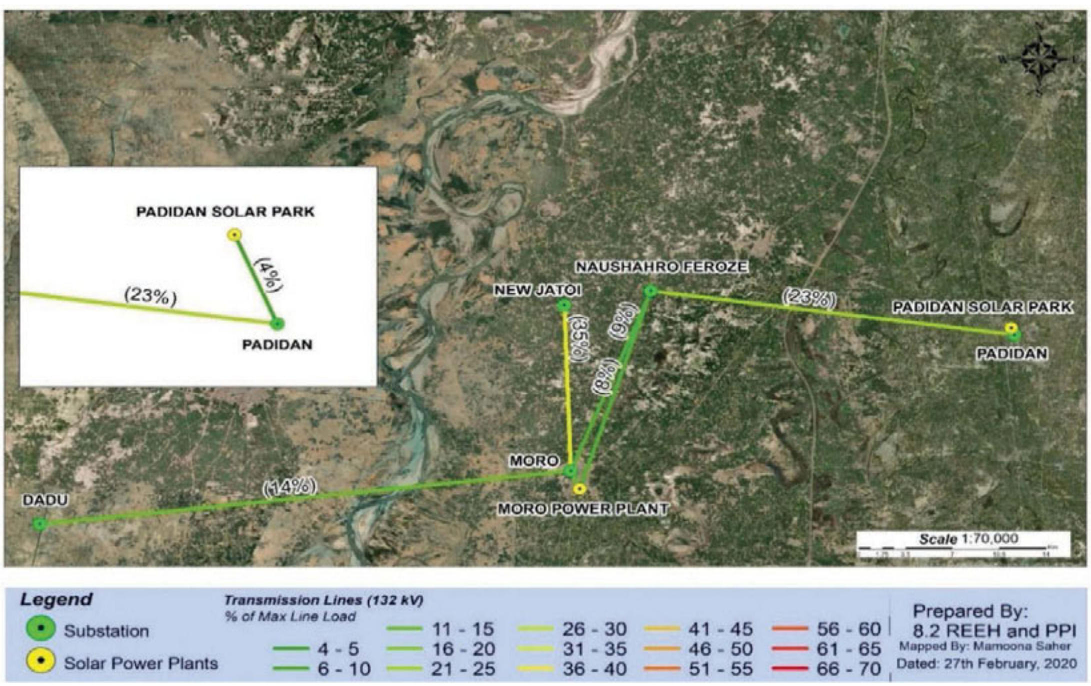
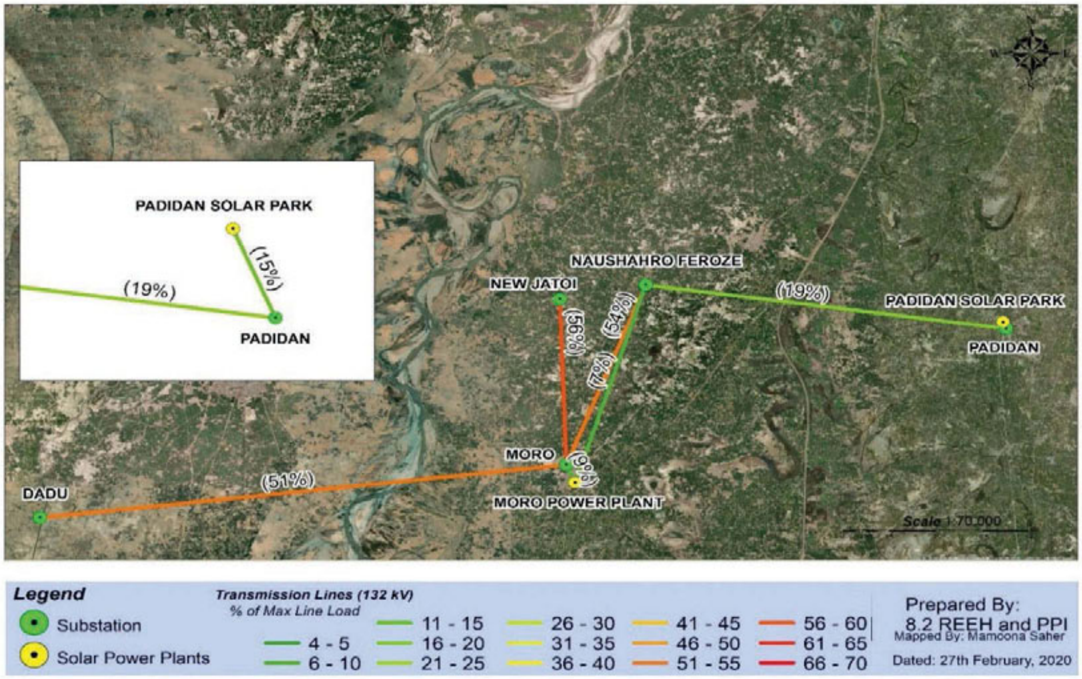


FIGURE 2-3: TRANSMISSION LINE LOADING FROM DADU (EVENING TIME)



2.9.1.2 Case study 2

The second example is of a proposed solar power plant in Punjab, namely the Alipur Solar Power Plant. The complete area of Dammarwala, Jatoi, Alipur, and Khairpur Sadat is being fed from the Muzaffargarh 220/132 kV grid station.

During the daytime, the solar power plant feeds the local load, and the electric loading on the main 132 kV line from Muzaffargarh is significantly lowered. At daytime, the loading of the line from Muzaffargarh to Jatoi is only 19 percent (see Figure 2-4), while the same transmission line reaches the loading of 37 percent during evening time when the output from solar plants becomes zero (see Figure 2-5). As per the loading of the line, the line loss during the daytime at the Muzaffargarh to Jatoi line is 0.38 MW because of the local source of power available during daytime, whereas it increases at evening time to a value of 1.16 MW when local solar generation is off.

2.10 CONCLUSION

As per the technical grid analysis of Chapter 2, the VRE plants that can be interconnected from a grid perspective are summarized in the Table 2-14.

Figures 2-6 and 2-7 show the resulting generation mixes for 2025 and 2030, respectively.

FIGURE 2-4: TRANSMISSION LINE LOADING FROM MUZAFFARGARH (DAYTIME)

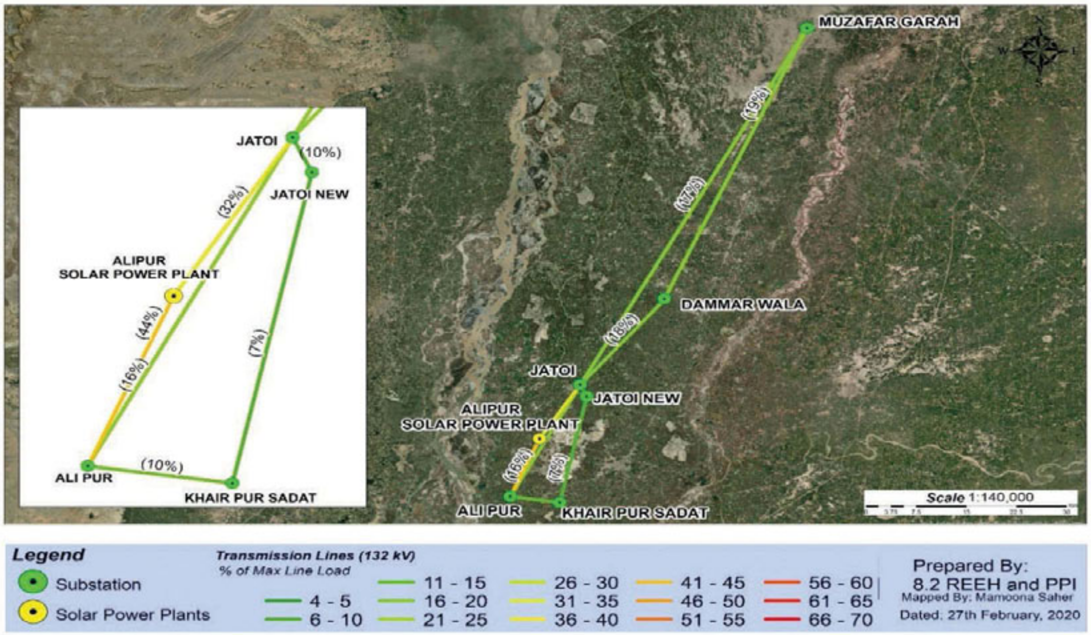


FIGURE 2-5: TRANSMISSION LINE LOADING FROM MUZAFFARGARH (EVENING TIME)

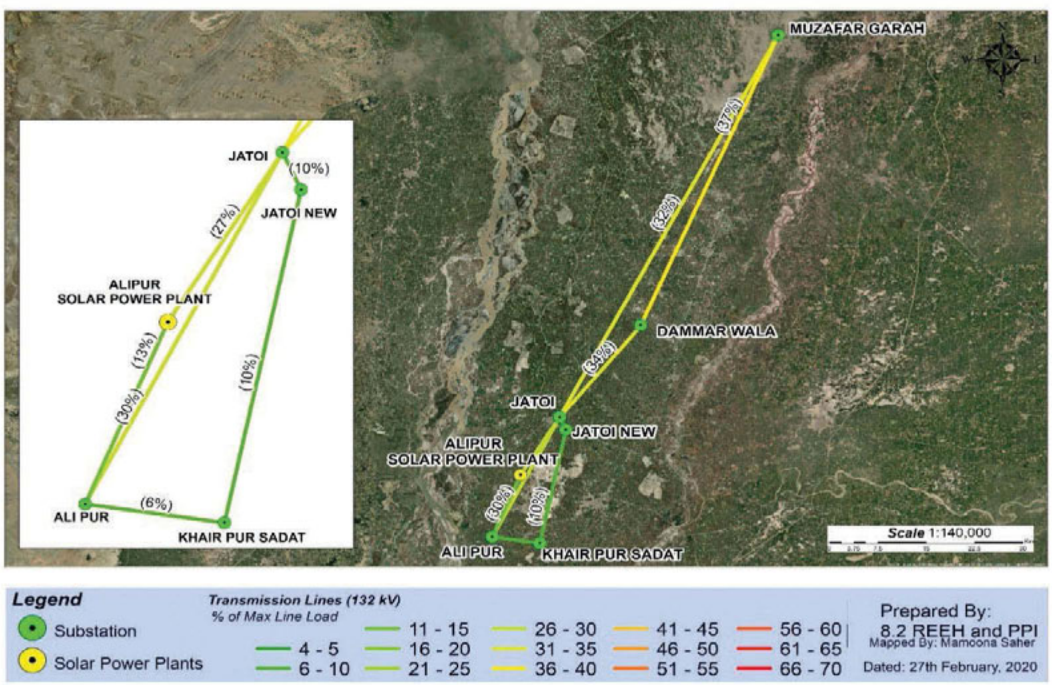


TABLE 2-14: SUMMARY OF VRE ADDITIONS UNTIL 2030

Province	Additions until 2023			Additions between 2023 and 2025			Additions between 2025 and 2030		
	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Sindh	480	700	1,180	900	1,350	2,250	500	950	1,450
Balochistan	800	1,050	1,850	500	650	1,150	4,000	2,150	6,150
Punjab	200	1,310	1,510	0	1,390	1,390	600	1,700	2,300
KPK	0	200	200	50	325	375	0	400	400
VRE Installed and Committed	2,095	1,140	3,235	150	50	200	0	100	100
Total VRE	3,575	4,400	7,975	1,600	3,765	5,365	5,100	5,300	10,400
Total Installed Generation	53,685 MW			61,941 MW			75,595 MW		
Percent VRE of Installed Generation	**14.9%**			**21.5%**			**31.4%**		

FIGURE 2-6: GENERATION MIX BY 2025

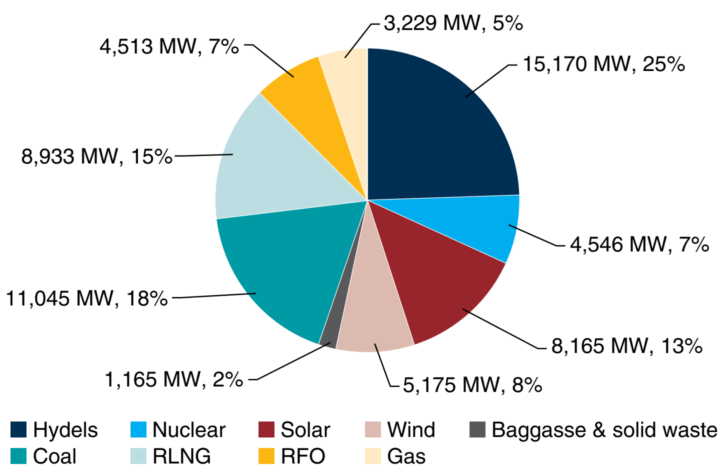
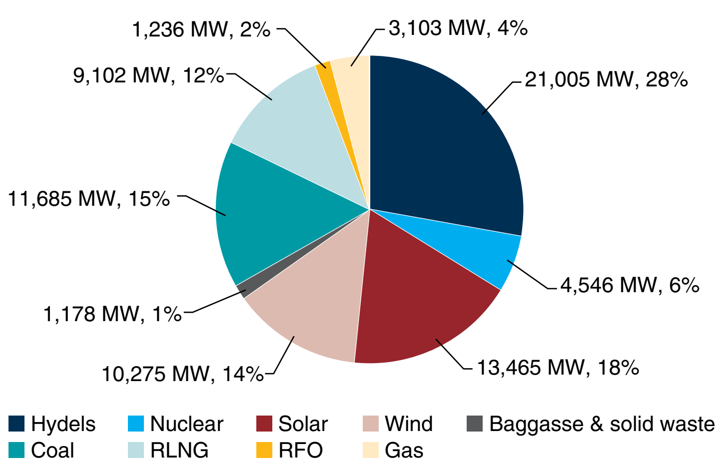


FIGURE 2-7: GENERATION MIX BY 2030



3. SHORTLISTING AND RANKING OF SOLAR AND WIND OPPORTUNITIES FOR PAKISTAN

3.1 INTRODUCTION

In this chapter, the results from the earlier chapters are combined and analyzed to provide the Government of Pakistan with propositions on prioritization of possible solar and wind power plant locations for both the near term and longer term. The result is 73 Potential Project Sites (PPSs) for solar, wind, or a combination thereof, located across Pakistan, of which 41 (38 PV sites and 3 hybrid sites) are identified as the best locations sufficient enough to reach the government goals of 20 percent of VRE installed capacity by 2025 and 30 percent by 2030. These sites are highly attractive for solar and/or wind power development, both in terms of resource availability and ease of grid integration. For all of these sites, basic attributes such as the site-specific generation profile, required upgrade grid costs, and others have been assessed, and an overall ranking of the sites has been performed to facilitate the development of these sites by the Government of Pakistan throughout the next years.

This analysis considers solar and wind power project developments that are already approved or likely to get approved soon, and other existing and future sources of power generation, as well as existing and planned transmission upgrades. In this analysis, financial attractiveness is considered, as well as some degree of provincial distribution, acceptable levels of system stability, and maximizing the benefits of co-location and siting with regard to daytime and seasonal generation patterns.

As part of this analysis, the portfolio effect of combining single assets into one portfolio was carefully assessed. The production profile of existing solar and wind plants has been simulated, as well as of the 73 opportunity sites, and compared them with the country demand profile. Of these 73 sites, 12 sites are suitable for co-location of solar and wind power plants as every potential wind project site was also evaluated positively for its solar power potential. Consequently, combined volatility and correlation with demand was simulated for the selected portfolios.

To develop a better understanding of the methodology deployed, an exemplary site of a development opportunity has been selected from Panjgur, in western Balochistan, and is presented in this section for in-depth discussion.

The details of the Potential Project Sites (PPSs) selected for this study are provided in Annex A.3, Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan.

3.2 APPROACH AND METHODOLOGY

In Chapter 1 of the Main Report, potential low-cost areas for solar and wind plants in Pakistan were identified and mapped, including the national transmission grid lines. In Chapter 2, the capacity of the grid lines and substations, the local energy demand of different areas and all existing and planned generation plants were considered. Additionally, the reliability of the transmission grid capacities in the specific areas was checked by considering the loss or tripping of any part of the transmission lines at any moment, and also by analyzing the short circuit levels and dynamic stability of the system. Based on this analysis in Chapter 2, 73 grid opportunity areas were identified in the attractive renewable energy zones for detailed analysis in Chapter 3. More specifically, wherever the software simulation of grid and load flow identified a free grid capacity of a minimum of 50 MW on a line or substation, the spot was marked as a grid opportunity area.

By using satellite images, a possible exact physical plant location (mostly barren land, if available) was mapped for each of the 73 grid opportunity areas in order to facilitate a feasible installation and potentially low land lease cost. These potential project sites are normally within a 10 km range of the grid opportunity spot.

Production patterns of wind and solar power plants have been modeled to simulate the local production profile and its volatility for all potential project sites. For each potential project site, the spot financial attractiveness and portfolio financial attractiveness for solar, wind, and hybrid setups was calculated to determine the best technology option and the financial feasibility of the given site.[11] For wind power, the underlying hourly wind data have been obtained from the Global Wind Atlas;[12] for solar power, the irradiation data or the specific yield, respectively, have been obtained from the Global Solar Atlas.[13]

In total, 73 grid-opportunity areas have been identified which have been further analyzed as potential project sites. Of these, 12 sites are suitable for co-location of solar and wind power plants, as every potential wind project site was also evaluated for its solar power potential, and the wind solar option always scores higher than the wind only option. As grid capacity utilization is a cost driver, the combination of solar and wind (which shows different generation patterns) makes technical and economic sense and makes the best use of available evacuation capacities. For the tender process, a technology-agnostic bidding process should be used that allows hybridization and incentivizes a high utilization of the given grid evacuation capacity.

In addition, 15 large-scale opportunity areas of GW size for additional solar PV and wind plants have been identified to allow a maximum solar and wind capacity addition for 2030 and beyond. For the power evacuation from these sites, new grid infrastructure would be required, the cost of which is considered in the cost calculation. To facilitate these large-scale sites, the government would need to take care of the development of this additional infrastructure. Besides the locations of Chaghi and Jhimpir—which are excellent hybrid locations—no other GW site has to be developed for meeting the required targets. **Details of the GW POAs are given in Annex A.3 for Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan.**

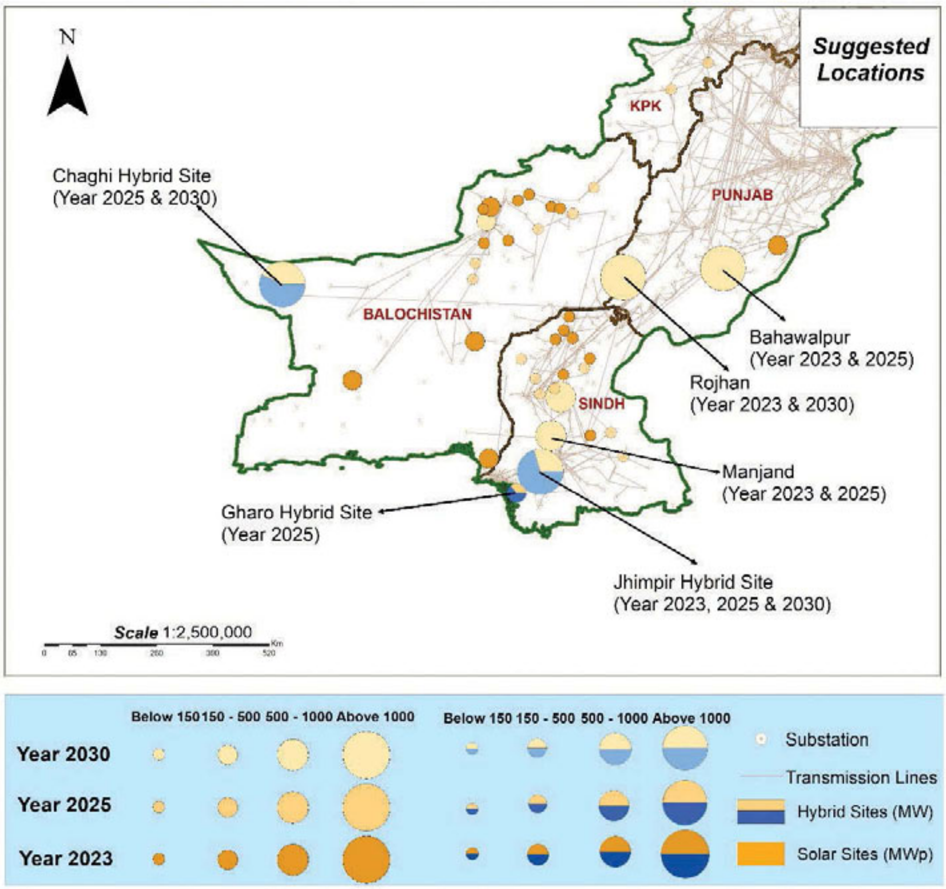
The potential project sites are geographically shown in Figure 3-1.

[11] Financial attractiveness is a relative score based upon the expected price of electricity for each POA a developer would offer to build the plant (US$/kWh). It is based on a scale of 1–10, with 1 being the least attractive case (highest cost of energy) and 10 the most attractive case (lowest cost of electricity). For details, please refer to Annex 1 where the concept is introduced. Here in this report, these attractiveness numbers are made site-specific. A site financial attractiveness is the attractiveness of the current PPS. The portfolio attractiveness is the weighted average attractiveness of the total portfolio of all selected PPSs, including the current PPS.

[12] https://globalwindatlas.info

[13] https://globalsolaratlas.info

FIGURE 3-1: IDENTIFIED SITES ACCORDING TO SIZE AND YEAR OR REALIZATION (ORANGE = SOLAR, BLUE = WIND)



For all sites, the hourly production output for the years 2012 to 2016 have been analyzed for both solar and wind resources to calculate the cumulative production patterns, capacity factors, and hybrid cost of electricity.[14] The use of multiple years gives a higher certainty to the result.

For all opportunity areas from the selected locations, solar, wind, or hybrid configurations of varying respective capacities have been analyzed for their capacity factors, hourly volatility of energy supply, expected CAPEX, financial attractiveness, and net present value of the specific potential project site (NPV).[15] This resulted in optimal technical setups and an overall portfolio to meet and optimize the GoP's

[14] Please note that the emphasis of the analysis is on volatility of production from sites and the portfolio, not on the average financial return over a period. For this reason, single year input data have been used for this analysis as here the volatility is highest. The financial results are the average of 5 years.

[15] The NPV for Pakistan (or CPPA as the power purchasing agency) is calculated against the alternative cost of fossil resources of US$0.1/kWh and a discount rate of 10 percent (taken from the Tractebel study performed in parallel to the study at hand, "Variable Renewable Energy Integration and Planning Study, Pakistan"), 2019/2020. So, the NPV value represents the economic benefit for Pakistan/CPPA in terms of electricity that is purchased at lower rates compared to fossil-based generation, across the next 25 years. While the value of US$0.1/kWh strongly determines the absolute NPV values, the ranking between the different NPVs is independent of the specific value.

TABLE 3-1: SCENARIO COMPARISON IN DIFFERENT SPOT YEARS

Year		2025			2030		
Scenario		S1 All Sites, Conventional Sizing	S2 All Sites, Optimization Sizing	S3 Sel. Sites Optimization Sizing	S1 All Sites, Conventional Sizing	S2 All Sites, Optimization Sizing	S3 Sel. Sites Optimization Sizing
Total Generation Capacity	MW	61,941	61,941	61,941	75,595	75,595	75,595
VRE Capacity (Solar + Wind)	MWp	13,340	15,050	12,481	23,740	28,237	23,801
VRE Capacity Share	%	21.50%	24.30%	20.10%	31.40%	37.40%	31.50%

VRE targets for 2025 and 2030, i.e., 20 percent and 30 percent of VRE generation capacity, respectively, as shown in Table 3-1.

The expected CAPEX, financial attractiveness, and NPV of each PPS is added up per scenario to evaluate the scenarios.

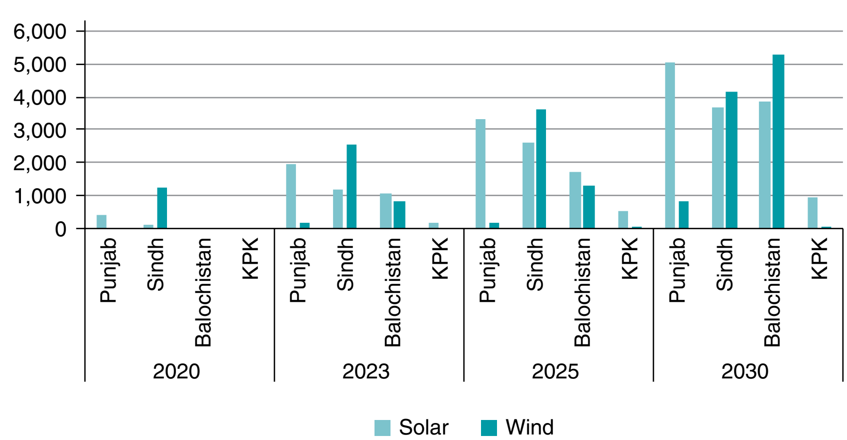
Scenario 1

Scenario 1 is based on conventional sizing. This means that the solar PV DC-to-AC ratio is about 120 percent, i.e., for a free grid capacity of 100 MW, 120 MWp of PV solar (total of nominal panel capacity) are used. For wind, 100 MW nominal installed capacity are used, and for hybrid sites, 100 MW wind plus 50 MWp PV are used, based on ratios which have been used so far by developers for the Jhimpir region.

Such sizing is historically based on the high cost of solar PV and is developer driven in order to maximize the return for the developer, but it does not optimize grid utilization.

This scenario matches the numbers from Chapter 2, with a total of 23,740 MW for 2030. The breakdown of capacity by province is shown in Figure 3-2.

FIGURE 3-2: PROPOSED INSTALLED CAPACITIES IN MW FOR 2020, 2023, 2025 AND 2030 ACCORDING TO SCENARIO 1



Scenario 2

By sizing the solar PV DC capacity for a given connection point, including a defined grid connection capacity with the goal of achieving minimal per-unit cost, a high DC-to-AC ratio or Inverter Load Ratio (ILR) was beneficial.

Based on technology cost assumptions, automated east-west (daily) single-axis tracking was evaluated as the cost-optimal technology setup and used as the base case for all further analysis. As east-west tracking has a lower noon peak than fixed structures due to tracking and the horizontal setup, significantly higher DC-to-AC ratios make sense. Depending on the site, ILR values of 110 percent up to 150 percent are optimal when taking into account costs of grid infrastructure costs and economies of scale.[16] The shedding of a few kWh per year is acceptable if this leads to a better utilization of the existing grid connection. See Table 3-3 for further details, where 179 MWp at 128 MW of line (= inverter) capacity (ILR of 1.40) leads to only 1 percent of losses ("production surplus" in table) during the year.

In Scenario 2, the GoP will be able to exceed the current VRE target at a better per-unit cost and with a higher utilization factor of the grid infrastructure. Through the most economic generation of solar and best usage of grid infrastructure, this sizing approach will allow for larger grid utilization factors, larger savings in power purchases by CPPA, and higher rates of emission reduction.

In addition to the optimization of sizing, hybrid sites have also been optimized for lowest costs, leading to higher numbers and different splits between wind and solar, according to the specific site characteristics. Only for two PPSs, Chaghi in Balochistan and Jhimpir in Sindh is wind actually cost-effective. For all other sites, a maximum utilization with solar PV is most cost-effective based on the taken cost assumptions for solar and wind plants; see Annex A.3 for Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan.

Scenario 2, applied to all grid-opportunity areas evaluated in Chapter 2, allows for up to a 37.4 percent of VRE share in 2030.

Scenario 3

In Scenario 2, the total MW numbers exceed the VRE targets due to higher sizing per site. In Scenario 3, the highest cost sites of Scenario 2 were then excluded to come back to the original 20 percent and 30 percent targets, thus using a smaller number of sites with more optimized sizing.

In this scenario, the official government targets are achieved with a lower number of sites and a lower total required investment cost compared to Scenario 1.

3.3 SIZING AND EVALUATION METHODOLOGY

3.3.1 Site Example

The energy production simulation tool used for this analysis was developed inhouse by the 8.2 Renewable Energy Experts group in 2010. It is based on an hourly analysis for one year (8,760 hours). For every hour, input parameters for a specific site, such as ambient temperature, solar power output, wind power

[16] It is assumed that the interest and return on equity for the power seller are the same in all cases.

output, etc., are determined. In this case, most information came from the Global Solar Atlas, the Global Wind Atlas, and the grid analysis performed in Chapter 2; based on these parameters, secondary values such as net generation by the power plant are calculated. This tool has been used to calculate technical and financial results for the whole year, including capacity factor, generation pattern, and NPV of the plant(s) to CPPA/GoP on the country level. All these are calculated for different technical setups of solar and wind power plant sizing.

It is assumed that Pakistan will be able to monetize on its effort to invest in clean energy through international emissions trading which is expected to pick up momentum. The value of emission reduction is not considered in the financial evaluation of this study, but is considered as an enormous separate benefit.

For an exemplary discussion of one site, a 128 MW grid capacity site is selected at Panjgur, in western Balochistan, as shown in Figure 3-3 and described in Table 3-2. The region is sparsely populated. The site is accessible via the existing road network which might, however, need to be upgraded. Panjgur site has some wind potential which allows the comparison of cases A–F; however, the most economical option turned out to be solar only for this site, as explained in the comparison of cases C and F.

FIGURE 3-3: SATELLITE IMAGE AND DEMARCATION OF THE PPS "PANJGUR" IN BALOCHISTAN

For the selected site, six different cases were run and evaluated based on their results. The cases are as follows:

- Case A — Conventional sizing of a fixed tilt solar PV plant at a DC-to-AC power ratio of 120 percent to the available grid capacity with fixed structure
- Case B — Conventional sizing of a solar PV and single-axis tracking structure (used for Scenario 1)
- Case C — Lowest-cost solar PV plant (tracking) with a site dependent DC-to-AC ratio of 110–150 percent to the available grid capacity (see explanation above) (used for Scenarios 2 and 3)

TABLE 3-2: INPUT PARAMETERS USED FOR PANJGUR, BALOCHISTAN[17]

Technical Assumptions		
Available Transmission Line Capacity (as per Chapter C)	MW	128
Distance to Line	km	2
Line Voltage	kV	132
Other Grid Connection Cost	USD million	0
Financial Assumptions (for NPV estimation only)		
Annual Inflation	%	6
Interest Rate	%	6
Discount Factor	%	10

Case D Solar PV plant (tracking) with a DC-to-AC power ratio of 110–150 percent to the available grid capacity plus storage case

Case E Wind-only case (for sites suitable for wind only)

Case F Capacity factor optimization by installation of a hybrid solar (tracking) and wind park (for sites suitable for wind only)

The summary results are given in Table 3-3 and are then discussed in detail for each case.

TABLE 3-3: SUMMARY CASE EVALUATION

Case	A	B	C	D	E	F
	Fixed PV	Tracked PV	Cost Minimum PV	Storage PV	Wind	Hybrid PV and Wind
PV MWp	153	153	179	179	0	100
Wind MW	0	0	0	0	130	72
Battery MWh	0	0	0	50	0	0
Production Surplus[18]	0%	0%	1%	0%	0%	1%
Initial GWh/a	294	354	409	412	391	446
Grid Utilization Factor (%)	27%	32%	37%	37%	35%	40%
Volatility Daytime (%)	42%	24%	23%	23%	62%	23%
Financial Attractiveness (0–10)[19]	8.5	9	9.3	8.1	6.9	7.9
NPV GoP/CPPA $, Millions	288	357	418	394	351	425

[17] These assumptions are uncertain until the time of tendering. As far as irradiation and plant performance is concerned, they can only be exactly determined at the end of a project's lifetime. Hence, the decision to build and finance the project must be taken under some uncertainty.

[18] Also called "generation shedding" or "clipping losses," i.e., the amount of VRE energy that cannot be exported to the grid due to the maximum power rating of the connection lines here (or in other kinds of analysis, which were not part of this study as they are more relevant for markets with higher RE penetration, due to a generation overload in the total national grid).

[19] Financial attractiveness is relative score based on expected cost of energy for each POA. It is based on a scale of 1–10, with 1 being the least attractive case (highest cost of energy) and 10 the most attractive case (lowest cost of energy).

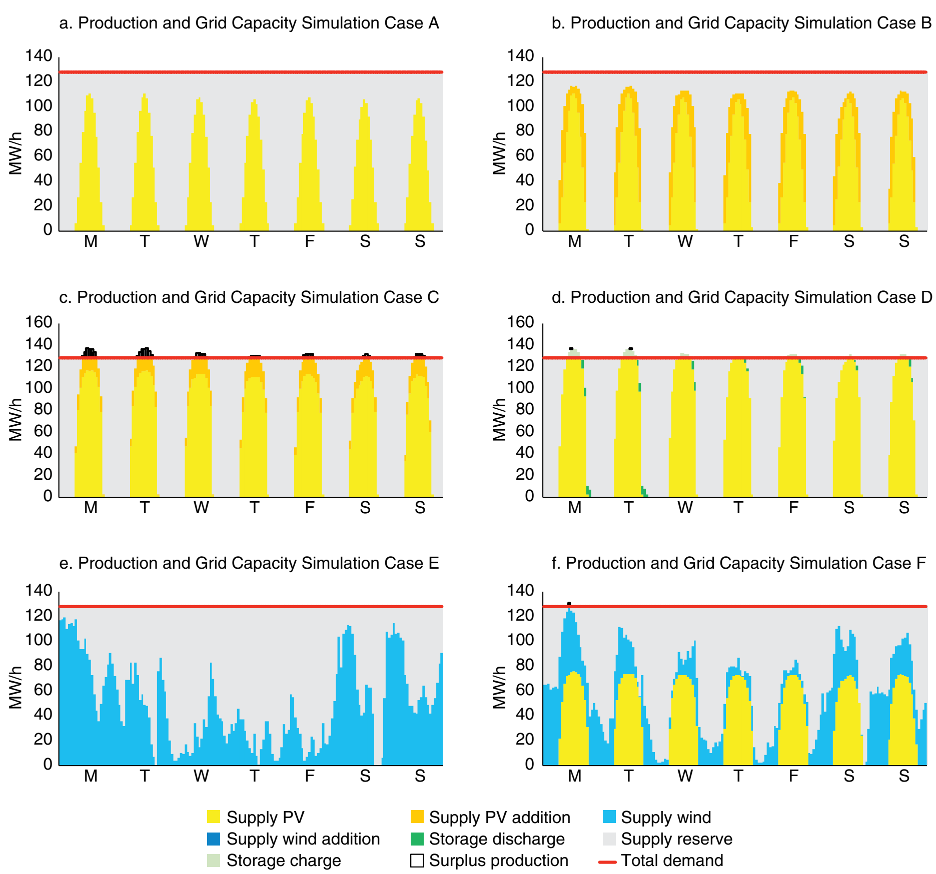
3.3.2 Site Analysis: Six Cases

In order to determine the optimal techno-economical setup, the six different cases listed above have been simulated and compared in detail. Figure D-4 shows snapshots of weekly output patterns of these six different cases for one week in July for the site of Panjgur, Balochistan. For all details of the analysis, refer to Annex A.3 for Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan. The following points can be observed:

The comparison of Case A and B demonstrates that tracked solar PV delivers a more balanced and higher output (panel B; orange: addition through tracking). For a given transmission grid evacuation capacity (here at 128 MW), this allows for a higher utilization of this limited line capacity and therefore, a higher annual output from that site. All sites analyzed for this study gave similar results, and this benefit also transfers into the financial viability as it outweighs additional costs of tracking at the assumed costs. Hence, it was decided to use a single-axis tracking system as a default for the next cases because it is more cost-effective.

Case C is the lowest-cost case. This is achieved by installation of additional DC capacity, i.e., solar panels (panel a; orange: additional panels output), along with the use of a single-axis tracker structure for generation of extra energy, resulting in a better utilization of the grid. The cost savings result from economies of scale and a lower grid connection cost per kWh, as more energy can be evacuated through

FIGURE 3-4: COMPARISON OF OUTPUT PATTERNS FOR A WEEK IN JULY FOR THE CASES A–F; MAXIMUM GRID EVACUATION CAPACITY 128 MW (RED LINE)



the same line. This sizing results in some surplus production above the line capacity at a few times over the year, which could be used under Dynamic Line Rating (DLR).

Case D includes a Battery Energy Storage System (BESS), allowing for even higher DC capacity. BESS has the additional benefits of displacement of generation from peak production time to peak consumption times (panel d; gray: storage charge; green: storage discharge); however, the cost for this improvement is comparatively high. That is also why only a small amount of storage (50 MWh) is analyzed here.

Case E shows the wind profile with its volatility (panel E).

Case F shows how solar and wind in a hybrid combination make use of their different generation patterns in order to achieve maximum utilization of the given line capacity (panel f; here both with a smaller capacity as before, as the available grid capacity needs to be utilized for the generation of both plants). This case has a higher NPV but lower financial attractiveness compared to Case C. This means that the energy produced in Case F is more expensive than that in Case C (lower financial attractiveness); however, more energy is being produced at a cost (which is still lower than the average grid generation cost), leading to a higher NPV. As there are many more potential sites available in Pakistan, the economically best option is therefore to use the case with the highest financial attractiveness for each site (Case C) and then select the sites according to their financial attractiveness, starting with the highest, until the desired amount of energy or installation capacity is reached.

These six cases have been evaluated for all sites. Table 3-3 shows the most relevant results for the specific site, Panjgur.

3.4 PORTFOLIO SELECTION

3.4.1 Introduction

To achieve maximum benefit through the implementation of solar and wind power plants on the POAs, the list of 73 grid opportunities or priority sites from Chapter 2 (including further options for future grid extension) have been ranked according to their financial attractiveness, where a higher attractiveness corresponds to a better economical per-unit cost of generation and grid evacuation. The result of this ranking is given in Annex A.3: Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan. In order to achieve this, a portfolio analysis has been performed with the aim of focusing on best-suited sites first, while maintaining an overall balance in terms of regional spread and generation profile. The outcome of this analysis is shared in Annex A.3. This ranking, however, is a suggestion and might be adjusted according to additional considerations by concerned government institutions.

The selection and prioritization of specific Potential Project Sites (PPSs) consider the effect of combining sites at different geographic locations of Pakistan. This is because a combination of different sites will give a different and better cumulative production profile in comparison to a single central site due to the changing microclimate and available sunlight. This analysis has taken the VRE portfolio of 73 geographic locations of Pakistan into account to understand the overall production pattern and its implications for the integration of a high share of VRE into the grid.

As a second benefit, the priority of sites can be influenced by selecting better fitting sites for a smoother and less volatile production pattern. This effect is called portfolio effect and is analyzed in detail in the portfolio theory, mainly for financial decision making between different investment cases. Pakistan is currently facing a similar situation of committing to a selection of VRE contracts. Hence the same analysis methodology has been applied whereby the portfolio effect of combining single assets into one portfolio was assessed. The portfolio production profile was simulated, leading to an evaluation of the production volatility. Furthermore, the production profile was compared with an estimated demand profile from a related study. Consequently, combined volatility and correlation with demand were simulated for the given portfolio.

The PPSs in **Scenario 1** are selected in a sequence derived from financial attractiveness (corresponding to the lowest to highest expected PPA price) in three lots: until 2023, 2023–2025, and 2025–2030. Scenario 1 assumes approximately a 120 percent DC-to-AC ratio for the sizing of solar systems system, i.e., a 100 MWp PV plant for 85 MW available grid capacity. This scenario matches with the numbers as proposed in Chapter 2.

Scenario 2 minimizes the overall generation costs of any PPS by better utilization of the grid capacity for the project sites, and sites are then prioritized by financial attractiveness.

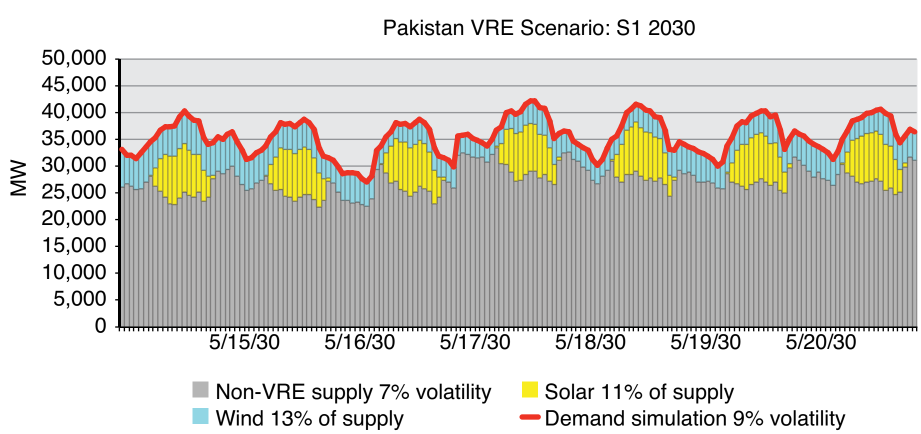
Scenario 3 selects the lowest cost sites from Scenario 2 and then again ranks them by financial attractiveness.

3.4.2 Scenario Load Patterns

Scenario 1

Figure 3-5 visualizes the nationwide production of solar and wind energy as well as non-VRE energy in hourly resolution of **Scenario 1** for one example week in May 2030. For this particular week, the volatility of demand to be managed by the grid management is 9 percent. After the introduction of solar and wind, the volatility to be managed remains at 7 percent. Thus, the introduction of VRE should not require significantly more reserve, based on its volatility. For this particular week, the overall volatility even

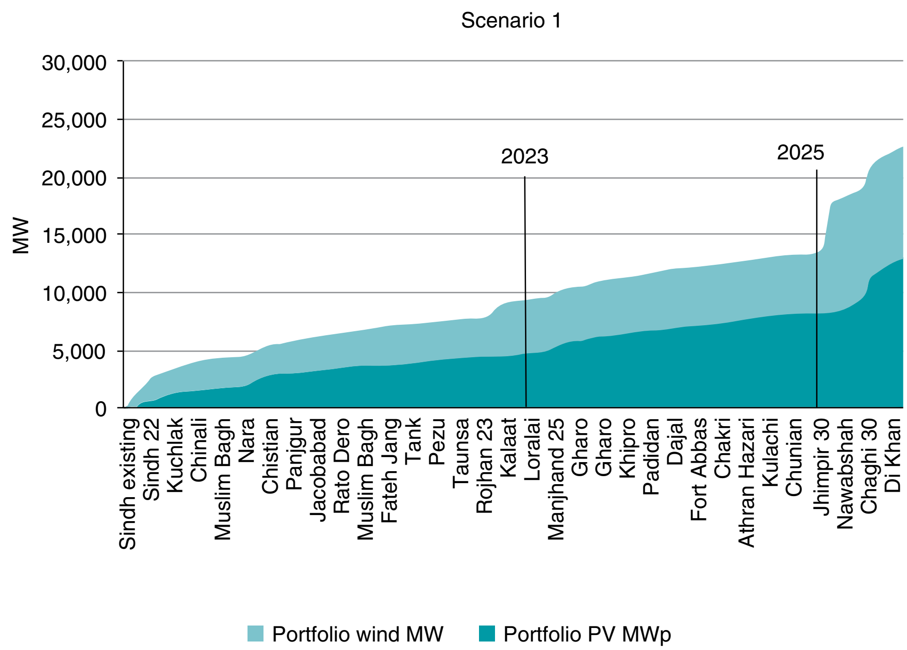
FIGURE 3-5: VOLATILITY WEEK 20 AND NPV FOR SCENARIO 1



Legend:

NPV vs. S1:	Annual difference for Pakistan to Scenario 1 to show the monetized value of S2 and S3
CF load:	Annual average grid utilization in percent
CF DC:	Annual DC capacity factor
Volatilities:	Volatility of current week
Wind/solar percent:	Percentage supply of technology in current week

FIGURE 3-6: CAPACITY BUILDUP FOR SCENARIO 1



reduces because of the correlation of VRE production and the demand profile. The correlation coefficient of hourly VRE production and load is 0.53.[20] This means that 53 percent of the volatility of the VRE production is following the volatility of the demand. Or simpler, the production profile of VRE is following the demand to a certain extent.

In Scenario 1, the VRE share is 31.5 percent in 2030, slightly above the target of 30.0 percent, as shown in Figure 3-6. The number can be reduced to exactly 30.0 percent by discarding some grid-opportunity areas.

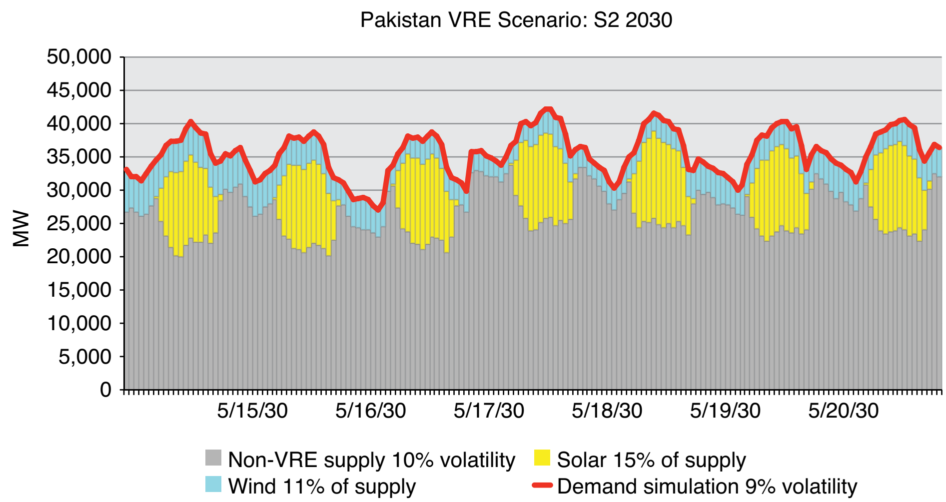
Scenario 2

Scenario 2 optimizes each PPS for its optimal size and technology. In the cost-optimal portfolio, extra capacity is installed for maximum utilization of the existing grid. In the case of solar, 110–150 MWp DC capacity can be installed on individual sites with 100 MW AC grid capacity. In wind energy, a maximum of an additional 5 percent can be observed. In this scenario, even though some kWh of energy produced will not be utilized and might be wasted, it is most cost-efficient in terms of the derived average cost per kWh for the country in total. This scenario results in more installed power from the beginning and a higher financial attractiveness score for the overall portfolio, resulting in higher profitability. The total discounted benefit in economic terms against Scenario 1 is US$4.8 billion for Pakistan.

Figure 3-7 visualizes the energy demand-supply curve for a sample week in May of a typical year in Scenario 2 for the entire country. As shown in Figure 3-7, solar PV is making a very stable contribution (although nighttime output is obviously zero, which cannot be adequately shown in the figure), whereas wind is more volatile. However, some locations such as Jhimpir or Chaghi, have a positive correlation

[20] The correlation coefficient, also known as *r*, is a measure of the strength and direction of the linear relationship between two variables, here demand and VRE supply. It is defined as the covariance of the variables divided by the product of their standard deviation. 0 means uncorrelated, 1 means a perfect match, and –1 means the most possible mismatch.

FIGURE 3-7: VOLATILITY WEEK 20 AND NPV FOR SCENARIO 2



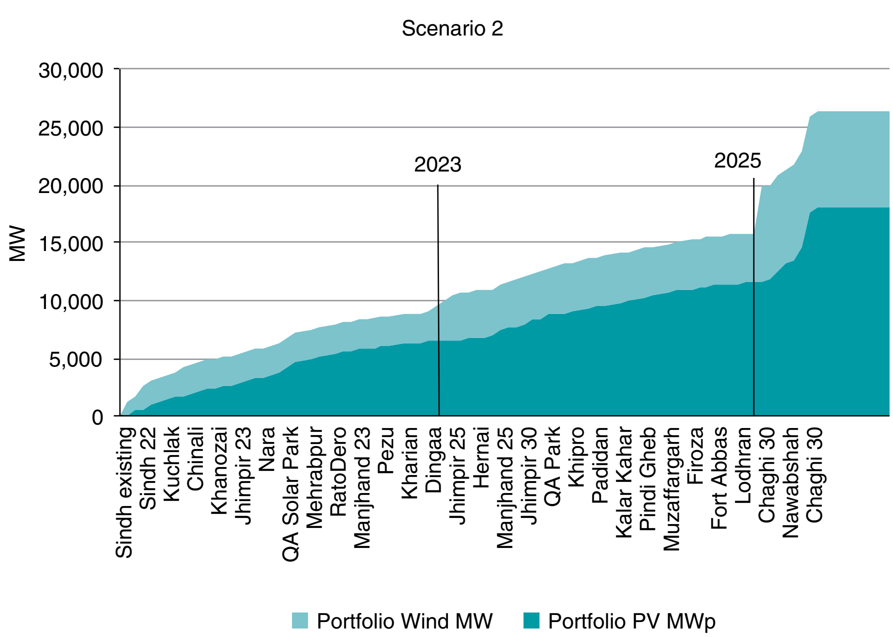
between wind production and overall electricity demand. Grid infrastructure for hybrid plants needs to be developed in these regions.

Scenario 2 has a much higher capacity installed than Scenario 1 and surpasses the strategic set targets of 20 percent VRE in 2025 and 30 percent in 2030 by an approximate 20 percent margin.

For 2030, with 37.4 percent of installed VRE in Scenario 2, the mix of installed VRE still has a good correlation with the expected demand profile, and hence, the need for dedicated reserve capacity for VRE is limited.

The overall exemplary capacity buildup for the cost optimal case is shown in Figure 3-8. The step changes toward the right (in 2025 and 2030) is attributed to wind power kicking in and a solar gigawatt park in the province of Chaghi.

FIGURE 3-8: CAPACITY BUILDUP FOR SCENARIO 2



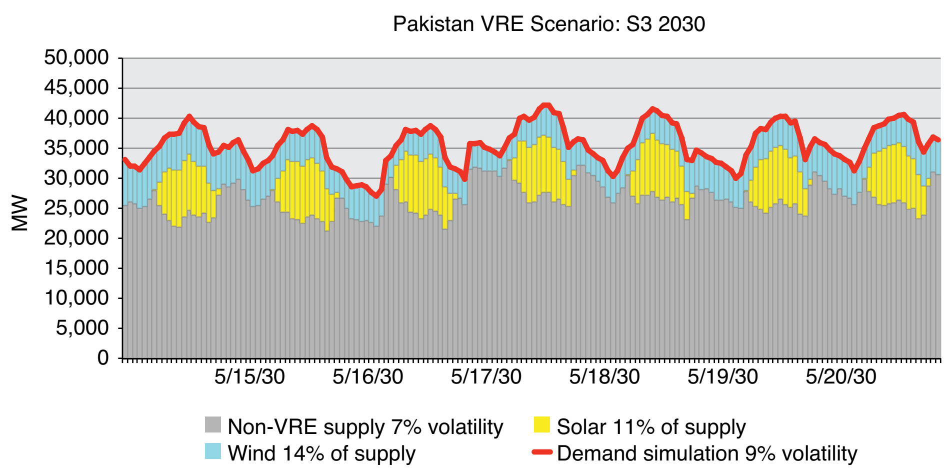
The correlation with the overall demand is with 0.48, some 0.04 points lower than Scenario 1. This is caused by more similar solar PV production than in Scenario 1.

Scenario 3

In Scenario 3, the explicit target of 20 percent or 30 percent VRE of installed capacity is met by reducing the sites from Scenario 2. In Scenarios 1 and 2, irrespective of the financial attractiveness of PPSs, all PPSs of 2023 and 2025 have been included. However, for Scenario 3, as the easiest and least controversial selection criteria, the grid opportunity areas with the lowest financial attractiveness have been ruled out in order to arrive again at the original government targets of 20 percent and 30 percent. Non-attractive wind locations have been replaced with attractive wind locations in the Jhimpir corridor. This results in a higher financial attractiveness of the overall portfolio. The total amount of VRE energy and expected profitability for Pakistan is similar to Scenario 2, however, with a much higher capital efficiency than Scenarios 1 and 2.

The correlation with the overall demand is with 0.54, the highest of the three scenarios, which confirms the selection criteria. Figures 3-9 and 3-10 show the sample week and capacity build-up as for the other two scenarios.

FIGURE 3-9: VOLATILITY WEEK 20 AND NPV FOR SCENARIO 3

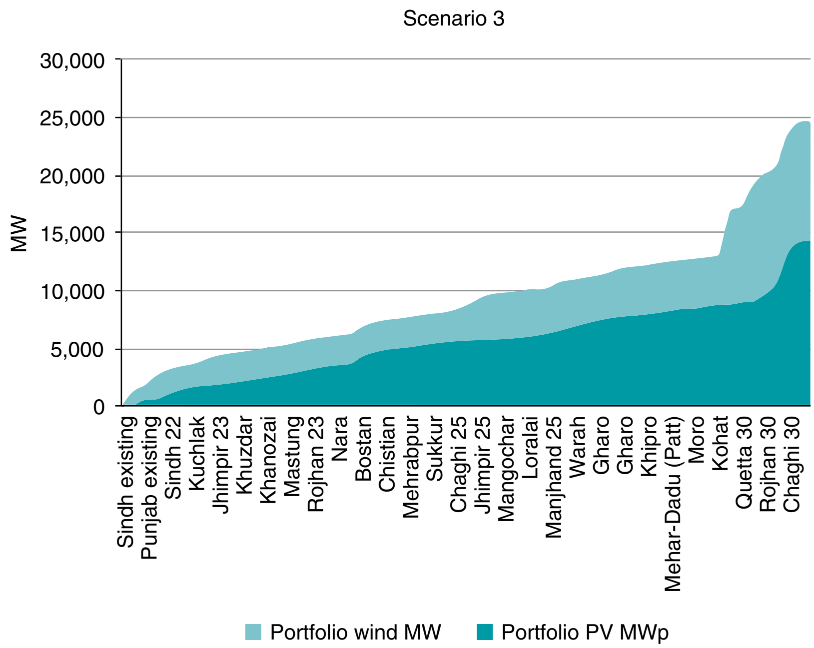


3.4.3 Scenario Comparison

The performed analysis shows that by combining multiple projects located across different geographic regions and featuring different technologies, the inherent volatility of fluctuations in renewable energy generation is mitigated to a certain extent, without specifically selecting well-matching sites. For instance, any sudden change in local wind resources or passing of clouds will affect wind and solar production, respectively. By combining multiple locations, such weather effects are averaged out. Lower production at one site will likely be balanced by higher production at another. On a national level, with around hundred operating sites, the average production will be smoother, and less capacity reserve is required. Due to reduced volatility, the energy production of the cumulative portfolio of renewables is more predictable than for a single location.

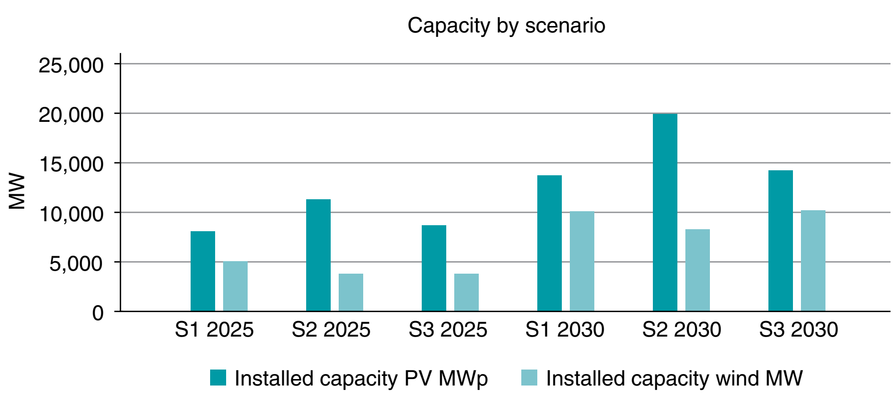
Any individual site has its unique correlation of output with the energy demand profile of the country. A site with a good correlation has a higher value for the country than a site with a lower correlation. However, due to the limited sites available compared to the VRE targets, not many of such choices can be made while meeting the VRE targets.

FIGURE 3-10: CAPACITY BUILDUP FOR SCENARIO 3



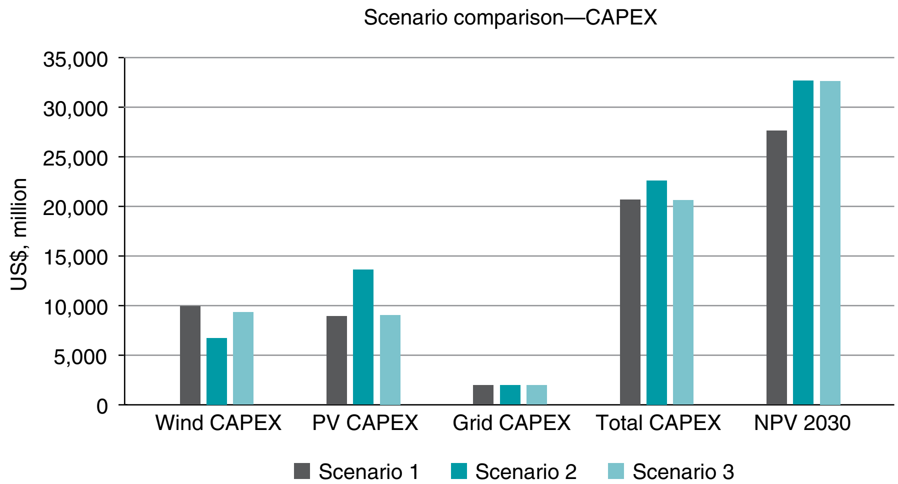
Figures 3-11 and 3-12 show the cumulative figures for installed capacity for the three different spot years (which are almost the same for Scenarios 1 and 3), according to the three scenarios, and the estimated CAPEX and NPV[21] figures for the three scenarios.

FIGURE 3-11: CUMULATIVE INSTALLED PV AND WIND CAPACITY IN S1, S2, AND S3



[21] The NPV for Pakistan (or CPPA as the power purchasing agency) is calculated against the alternative cost of fossil resources of US$0.1 /kWh and a discount rate of 10 percent (taken from the Tractebel study performed in parallel to the study at hand, "Variable Renewable Energy Integration and Planning Study, Pakistan"), 2019/2020. The NPV value represents the economic benefit for Pakistan/CPPA in terms of electricity, which is purchased at lower rates compared to fossil-based generation, across the next 25 years. While the value of US$0.1 /kWh strongly determines the absolute NPV values, the ranking between the different NPVs is independent of the specific value.

FIGURE 3-12: FINANCIAL COMPARISON OF THE THREE SCENARIOS



Scenario 3 has the highest financial attractiveness, is the most capital resource-efficient, and has the highest economic benefits (NPV) for Pakistan at the same time. For this reason, the priority sites selected by Scenario 3 are proposed as the optimal scenario to be followed.

For the financial parameters of the PPSs discussed in this analysis, costs for necessary grid improvements, as well as standard lease rates for land, have been included. On the other side, benefits for CO_2 emissions savings have not been included in the NPV calculation; the NPV in this study solely represents the benefit of low-cost power generation.

Table 3-4 shows the financial summary figures (estimated required CAPEX, financial attractiveness, and expected NPV for the country) for the three different scenarios.

TABLE 3-4: CAPITAL EFFICIENCY OF SCENARIOS

All Values Are in Million Dollars	Wind CAPEX	PV CAPEX	Grid CAPEX	Total CAPEX	Financial Attractiveness	NPV	Capital Efficiency
Scenario 1	9,753	8,967	1,780	20,501	8.1	27,379	134%
Scenario 2	7,096	13,523	1,781	22,400	8.2	32,196	144%
Scenario 3	9,216	9,091	2,209	20,516	8.6	32,124	157%

The capital efficiency is defined as a quotient of the NPV of the total scenario divided by the required CAPEX. For Pakistan, capital efficiency is a very important criteria, especially as more of the required investment will be in foreign exchange dominated sources. As mentioned above, this efficiency comes out highest for Scenario 3. For this reason, we recommend pursuing all identified PPSs as simulated in Scenario 3.

Table 3-5 shows the key parameters of all the scenarios.

TABLE 3-5: KEY PARAMETERS OF S1, S2, AND S3 FOR DIFFERENT SPOT YEARS

Year			2025			2030		
Scenario			**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Total Generation Capacity	Grid	MW	61,941	61,941	75,595	75,595	75,595	75,595
Installed Capacity	VRE DC	MWp	15,050	12,481	23,740	28,237	23,801	23,801
Installed Capacity	VRE DC	%	24.3%	20.2%	31.4%	37.4%	31.5%	31.5%
Installed Capacity	VRE AC	MW	10,735	9,155	18,465	18,688	16,723	16,723
Installed Capacity	AC	%	17%	15%	24%	25%	22%	22%
Energy	Country	GWh	223,833	223,833	284,879	284,879	284,879	284,879
Energy	VRE	GWh	35,775	31,522	64,808	71,584	68,597	68,597
Energy	VRE kWh	%	16%	14%	23%	25%	24%	24%
CAPEX		US$, million	10,723	8,816	20,501	22,400	20,516	20,516
Capacity Factor	VRE DC	%	27%	29%	31%	29%	33%	33%
Grid Utilization Factor	VRE AC	%	38%	39%	40%	44%	47%	47%
Financial Attractiveness		0–10	7.9	8.2	8.1	8.2	8.6	8.6
Financial Benefit: NPV		US$, million	15,471	14,114	28,642	32,196	32,124	32,124
Volatility	Country	stdv load	26%	26%	26%	26%	26%	26%
Volatility	VRE	stdv VRE	27%	26%	28%	30%	28%	28%

The breakdown between the technologies and provinces shown in Table 3-6.

TABLE 3-6: PROVINCE-WISE VRE CAPACITY BREAKDOWN UNDER DIFFERENT SCENARIOS

Capacity Split			S1	S2	S3	S1	S2	S3
Installed Capacity	PV	MWp	8,165	11,295	8,726	13,465	19,982	13,546
Installed Capacity	Wind	MW	5,175	3,755	3,755	10,275	8,255	10,255
Balochistan	VRE	MWp	3,000	3,016	3,016	9,150	10,196	10,196
KPK	VRE	MWp	575	762	280	975	1,282	280
Punjab	VRE	MWp	3,540	4,507	2,420	5,840	8,304	3,290
Sindh	VRE	MWp	6,225	6,765	6,765	7,775	8,455	10,035

Table 3-7 shows key output parameters for the 73 Potential Project Sites (PPSs) using conventional sizing (Scenario 1). For some cases, hybrid configurations are analyzed. As the table differentiates between years and therefore mentions phased sites more than once, and as it includes existing sites, the total row number is 100 (instead of 73). VRE plants mentioned as "existing" are the ones who have achieved Commercial Operation Date (COD), whereas "Punjab 22" and "Sindh 22" represent VRE plants that have been considered as confirmed and are to be constructed soon (before 2023) as explained in Section 3.5 "Adjustment of Existing LOIs." Suggested plants are proposed in stages, and "23," "25," and "30" represent the spot years as per NTDC requirement.

TABLE 3-7: KEY OUTPUT PARAMETERS FOR THE POTENTIAL PROJECT SITES (PPSs) USING CONVENTIONAL SIZING (SCENARIO 1)

Year	Province	Location	Technology	MW Selected	Site Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	Portfolio Capital Factor Grid (%)	MWh VRE Production (cumulative)
2019	Sindh	Sindh existing	PV	100	0.00		0.27	27.35	191,649
2019	Sindh	Sindh existing	Wind	1,235	0.00		0.57	35.30	4,066,061
2019	Punjab	Punjab existing	PV	400	0.00		0.61	30.31	4,978,497
2022	Sindh	Sindh 22	Wind	860	9.99	7.48	0.60	35.49	8,502,258
2022	Sindh	Sindh 22	PV	400	8.75	7.59	0.61	34.77	9,304,856
2022	Punjab	Punjab 22	PV	240	7.30	7.57	0.60	34.14	9,733,935
2023	Balochistan	Kuchlak	PV	200	9.74	7.68	0.60	34.06	10,217,672
2023	Sindh	Jhimpir 23	Wind	480	9.19	7.91	0.60	35.65	12,118,128
2023	Balochistan	Khanozai	PV	100	9.08	7.94	0.60	35.58	12,359,717
2023	Balochistan	Mastung	PV	100	8.76	7.95	0.59	35.49	12,591,251
2023	Balochistan	Panjgur	Hybrid	300	7.97	7.95	0.54	36.23	13,463,279
2023	Balochistan	Khuzdar	Hybrid	300	7.87	7.95	0.54	36.93	14,324,292
2023	Sindh	Nara	PV	50	7.73	7.95	0.59	36.84	14,426,950
2023	Punjab	QA Solar Park Bahawalpur 23	PV	500	7.60	7.93	0.57	35.72	15,318,243
2023	Balochistan	Hub	PV	150	7.59	7.92	0.56	35.49	15,616,553
2023	Punjab	Chistian	PV	300	7.58	7.91	0.55	34.93	16,149,812
2023	Balochistan	Chinali	Hybrid	150	7.32	7.89	0.50	35.16	16,564,567
2023	Balochistan	Boston	PV	100	7.26	7.89	0.53	35.04	16,765,284
2023	Balochistan	Muslim Bagh	Hybrid	150	7.26	7.87	0.51	35.25	17,177,105
2023	Balochistan	Draganda	Hybrid	150	7.26	7.86	0.51	35.46	17,588,606
2023	Sindh	Sangar (Deh 22 Jamrao)	PV	100	7.01	7.85	0.53	35.32	17,783,163
2023	Sindh	Jacobabad	PV	100	6.91	7.84	0.53	35.17	17,971,301
2023	Sindh	Mehrabpur	PV	100	6.90	7.83	0.53	35.03	18,161,075
2023	Sindh	Sukkur	PV	100	6.86	7.82	0.52	34.90	18,350,011
2023	Sindh	Rato Dero	PV	100	6.86	7.81	0.52	34.76	18,536,587
2023	Balochistan	Mach	Hybrid	150	6.81	7.79	0.51	34.93	18,931,166
2023	Sindh	Shikarpur	PV	100	6.58	7.78	0.52	34.78	19,112,364
2023	Punjab	Fateh Jang	PV	100	6.03	7.76	0.50	34.63	19,284,186
2023	Punjab	Ahamadal	PV	50	5.98	7.75	0.50	34.55	19,371,004
2023	Sindh	Manjhand 23	PV	50	5.80	7.74	0.50	34.50	19,470,523
2023	KPK	Tank	PV	50	5.71	7.73	0.50	34.42	19,554,766
2023	KPK	Karak	PV	50	5.45	7.72	0.50	34.34	19,637,606
2023	Punjab	Dina	PV	100	5.44	7.71	0.50	34.18	19,801,055
2023	KPK	Pezu	PV	100	5.40	7.69	0.49	34.03	19,964,080
2023	Punjab	Kharian	PV	50	5.19	7.68	0.49	33.95	20,044,523
2023	Punjab	Taunsa	PV	50	4.61	7.66	0.49	33.87	20,121,523
2023	Punjab	Noorsar	PV	30	4.54	7.66	0.49	33.82	20,170,096
2023	Punjab	Dingaa	PV	30	4.05	7.65	0.49	33.78	20,218,774
2023	Punjab	Rojhan 23	Hybrid	300	3.88	7.54	0.49	33.78	20,813,866
2025	Sindh	Jhimpir 25	Wind	650	9.89	7.80	0.51	34.72	23,371,146

(continues)

TABLE 3-7: *CONTINUED*

Year	Province	Location	Technology	MW Selected	Site Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	Portfolio Capital Factor Grid (%)	MWh VRE Production (cumulative)
2025	Balochistan	Chaghi 25	Wind	500	9.85	7.97	0.54	35.60	25,522,645
2025	Balochistan	Kalaat	PV	100	9.01	7.98	0.54	35.57	25,762,226
2025	Balochistan	Manochar	PV	100	8.98	7.99	0.53	35.53	26,001,994
2025	Balochistan	Hernai	PV	100	8.80	8.00	0.53	35.49	26,235,053
2025	Balochistan	Loralai	PV	50	8.54	8.00	0.53	35.46	26,348,189
2025	Balochistan	Musafirpur	PV	50	8.53	8.00	0.53	35.44	26,460,844
2025	Balochistan	Chaghi 25	PV	250	8.23	8.01	0.52	36.20	27,028,984
2025	Sindh	Jhimpir 25	PV	300	8.09	8.01	0.51	37.00	27,625,274
2025	Sindh	Gharo	PV	100	7.62	8.01	0.51	37.25	27,816,481
2025	Punjab	QA Park Bahawalpur 25	PV	300	7.59	8.00	0.50	36.87	28,351,257
2025	Sindh	Warah	PV	100	7.55	7.99	0.50	36.79	28,562,989
2025	Sindh	Gharo	Wind	200	7.46	7.98	0.51	36.79	29,207,540
2025	Sindh	Manjhand 25	Hybrid	550	7.46	7.96	0.51	36.95	30,466,482
2025	Sindh	Moro	PV	50	6.98	7.96	0.51	36.90	30,562,113
2025	Sindh	Rohri	PV	100	6.96	7.95	0.50	36.79	30,750,909
2025	Sindh	Khipro	PV	100	6.92	7.95	0.50	36.70	30,942,843
2025	Sindh	Umarkot	PV	100	6.83	7.94	0.50	36.60	31,136,142
2025	Sindh	Mehar-Dadu line (Patt)	PV	100	6.72	7.93	0.50	36.50	31,323,306
2025	Sindh	Padidan	PV	100	6.46	7.92	0.50	36.41	31,515,532
2025	KPK	Bannu	PV	100	6.13	7.91	0.51	36.30	31,690,830
2025	Punjab	Dajal	PV	50	5.94	7.91	0.51	36.24	31,776,854
2025	Punjab	Kallar Kahar	PV	100	5.81	7.90	0.51	36.13	31,946,705
2025	Punjab	Firoza	PV	50	5.80	7.89	0.51	36.08	32,034,211
2025	Punjab	Fort Abbas	PV	50	5.68	7.88	0.50	36.02	32,117,684
2025	Punjab	Alipur	PV	100	5.67	7.87	0.50	35.91	32,286,445
2025	Punjab	Hasilpur	PV	100	5.55	7.86	0.50	35.80	32,451,358
2025	Punjab	Chakri	PV	100	5.54	7.85	0.50	35.69	32,618,496
2025	Punjab	Pindi Gheb	PV	100	5.53	7.84	0.50	35.58	32,784,476
2025	KPK	Kohat	PV	100	5.51	7.83	0.50	35.47	32,949,756
2025	Punjab	Athran Hazari	PV	100	5.50	7.81	0.50	35.37	33,114,236
2025	Punjab	Muzaffargarh	PV	100	5.47	7.80	0.50	35.26	33,278,611
2025	Punjab	Darya Khan	PV	100	5.31	7.79	0.50	35.16	33,440,065
2025	KPK	Kulachi	PV	100	5.29	7.78	0.50	35.05	33,605,264
2025	Punjab	Rangpur	PV	50	5.20	7.77	0.49	35.00	33,686,373
2025	Punjab	Lodhran	PV	30	5.11	7.77	0.49	34.97	33,737,042
2025	Punjab	Chunian	PV	30	4.90	7.76	0.49	34.94	33,785,350
2025	KPK	Warsak	Hybrid	75	4.45	7.75	0.49	34.95	33,945,622
2025	Punjab	Habib abad	PV	30	4.01	7.74	0.49	34.92	33,993,961
2030	Sindh	Jhimpir 30	Wind	500	9.77	7.85	0.50	35.32	35,930,751
2030	Balochistan	Chaghi 30	Wind	4000	9.38	8.35	0.58	38.86	53,142,749
2030	Balochistan	Quetta 30	PV	150	9.24	8.35	0.58	38.80	53,498,504

TABLE 3-7: *CONTINUED*

Year	Province	Location	Technology	MW Selected	Site Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	Portfolio Capital Factor Grid (%)	MWh VRE Production (cumulative)
2030	Sindh	Nawabshah Solar Park	PV	400	8.11	8.35	0.57	38.53	54,271,436
2030	Sindh	Jhimpir 30	PV	350	7.94	8.34	0.57	39.01	54,949,848
2030	Sindh	Wahi Pandhi Dadu	PV	300	7.62	8.34	0.56	38.79	55,512,561
2030	Balochistan	Chaghi 30	PV	2000	7.48	8.27	0.54	41.97	60,057,685
2030	Punjab	DG Khan	PV	500	7.03	8.25	0.54	41.48	60,902,295
2030	Punjab	Rahim yar Khan	PV	400	7.03	8.24	0.53	41.12	61,598,552
2030	KPK	DI Khan	PV	400	6.81	8.23	0.53	40.75	62,257,085
2030	Punjab	Jauharabad	PV	500	5.84	8.20	0.52	40.27	63,023,098
2030	Punjab	Rojhan 30	Hybrid	900	5.10	8.11	0.53	40.07	64,808,372

Scenario 1 is based on a conventional sizing, whereas Scenario 2 uses a progressive approach to do optimal sizing of the plants. As a result, the total MW numbers exceed the VRE targets due to higher sizing per site. Optimal sizing of the 73 proposed sites is given in Table 3-8. Again, due to year differentiation existing sites, the total row number is more than 73.

TABLE 3-8: KEY OUTPUT PARAMETERS FOR THE POTENTIAL PROJECT SITES (PPSs) USING OPTIMAL SIZING (SCENARIO 2)

Year	Province	Location	Technology	MW Selected	Spot Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	MWh VRE Production (cumulative)	Portfolio Capital Factor Grid (%)
2019	Sindh	Sindh existing	PV	100			0.27	191,649	27
2019	Sindh	Sindh existing	Wind	1,235			0.57	4,066,061	35
2019	Punjab	Punjab existing	PV	400			0.61	4,978,497	30
2022	Sindh	Sindh 22	Wind	860	9.99	7.48	0.60	8,502,258	35
2022	Sindh	Sindh 22	PV	480	8.77	7.61	0.60	9,465,375	35
2022	Punjab	Punjab 22	PV	300	7.59	7.61	0.60	10,001,724	35
2023	Balochistan	Kuchlak	PV	200	9.74	7.71	0.59	10,485,461	35
2023	Balochistan	Panjgur	PV	254	9.58	7.81	0.58	11,085,162	35
2023	Sindh	Jhimpir 23	Wind	450	9.30	8.01	0.59	12,858,388	36
2023	Balochistan	Chinali	PV	132	9.29	8.04	0.59	13,173,888	36
2023	Balochistan	Khuzdar	PV	244	9.24	8.09	0.58	13,724,835	36
2023	Balochistan	Muslim Bagh	PV	132	9.12	8.11	0.57	14,032,469	36
2023	Balochistan	Khanozai	PV	120	9.11	8.13	0.57	14,315,144	36
2023	Balochistan	Draganda	PV	132	9.10	8.15	0.56	14,621,989	36
2023	Balochistan	Mastung	PV	120	8.87	8.17	0.56	14,895,459	36
2023	Sindh	Jhimpir 23	PV	200	8.27	8.17	0.55	15,293,946	39
2023	Punjab	Rojhan 23	PV	290	8.25	8.17	0.54	15,875,830	39
2023	Balochistan	Hub	PV	210	7.86	8.17	0.53	16,285,724	39

(continues)

TABLE 3-8: *CONTINUED*

Year	Province	Location	Technology	MW Selected	Spot Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	MWh VRE Production (cumulative)	Portfolio Capital Factor Grid (%)
2023	Sindh	Nara	PV	60	7.74	8.16	0.53	16,408,912	38
2023	Balochistan	Mach	PV	132	7.72	8.16	0.52	16,670,516	38
2023	Balochistan	Bostan	PV	130	7.69	8.15	0.52	16,930,937	38
2023	Punjab	QA Solar Park Bahawalpur 23	PV	650	7.60	8.11	0.51	18,089,618	38
2023	Punjab	Chistian	PV	390	7.58	8.09	0.50	18,782,855	37
2023	Sindh	Sanghar (Deh 22 Jamrao)	PV	140	7.50	8.09	0.49	19,053,498	37
2023	Sindh	Mehrabpur	PV	140	7.37	8.08	0.49	19,318,375	37
2023	Sindh	Jacobabad	PV	140	7.35	8.07	0.49	19,580,722	37
2023	Sindh	Sukkur	PV	140	7.33	8.06	0.49	19,844,175	37
2023	Sindh	Rato Dero	PV	140	7.31	8.05	0.48	20,104,772	37
2023	Sindh	Shikarpur	PV	140	7.07	8.03	0.48	20,358,335	37
2023	Punjab	Fateh Jang	PV	140	6.50	8.02	0.48	20,597,325	37
2023	Sindh	Manjhand 23	PV	65	6.18	8.00	0.48	20,726,639	37
2023	Punjab	Ahamadal	PV	65	6.01	7.99	0.48	20,839,398	37
2023	Punjab	Dina	PV	140	5.98	7.97	0.48	21,067,825	37
2023	KPK	Pezu	PV	140	5.96	7.95	0.47	21,295,930	37
2023	KPK	Tank	PV	65	5.74	7.94	0.47	21,405,446	37
2023	KPK	Karak	PV	65	5.50	7.93	0.47	21,513,135	37
2023	Punjab	Kharian	PV	65	5.22	7.91	0.47	21,617,710	37
2023	Punjab	Noorsar	PV	42	4.68	7.90	0.47	21,685,709	37
2023	Punjab	Taunsa	PV	70	4.67	7.89	0.47	21,793,509	37
2023	Punjab	Dingaa	PV	42	4.32	7.88	0.47	21,861,558	37
2025	Balochistan	Chaghi 25	Wind	500	9.85	8.05	0.49	24,013,058	38
2025	Sindh	Jhimpir 25	Wind	500	9.70	8.18	0.51	25,976,394	38
2025	Balochistan	Kalaat	PV	120	9.08	8.19	0.50	26,258,076	38
2025	Balochistan	Manochar	PV	120	9.05	8.20	0.50	26,539,666	38
2025	Balochistan	Hernai	PV	120	8.92	8.20	0.50	26,815,399	38
2025	Balochistan	Loralai	PV	50	8.54	8.21	0.50	26,928,535	38
2025	Balochistan	Musafirpur	PV	50	8.53	8.21	0.50	27,041,190	38
2025	Sindh	Manjhand 25	PV	500	8.33	8.21	0.49	28,036,381	38
2025	Balochistan	Chaghi 25	PV	250	8.23	8.21	0.49	28,604,522	38
2025	Sindh	Warah	PV	130	7.92	8.21	0.48	28,877,172	38
2025	Sindh	Jhimpir 25	PV	250	7.85	8.20	0.48	29,372,588	39
2025	Sindh	Gharo	PV	120	7.64	8.20	0.48	29,600,758	39
2025	Punjab	QA Solar Park Bahawalpur 25	PV	390	7.60	8.18	0.47	30,295,967	39
2025	Sindh	Gharo	Wind	210	7.48	8.17	0.48	30,969,843	39
2025	Sindh	Rohri	PV	140	7.41	8.16	0.48	31,233,009	39
2025	Sindh	Khipro	PV	140	7.40	8.16	0.47	31,500,088	39
2025	Sindh	Umarkot	PV	140	7.32	8.15	0.47	31,768,622	39
2025	Sindh	Mehar-Dadu line (Patt)	PV	140	7.23	8.14	0.47	32,030,323	39

TABLE 3-8: *CONTINUED*

Year	Province	Location	Technology	MW Selected	Spot Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	MWh VRE Production (cumulative)	Portfolio Capital Factor Grid (%)
2025	Sindh	Padidan	PV	140	7.08	8.13	0.47	32,298,141	39
2025	Sindh	Moro	PV	65	7.01	8.13	0.47	32,422,461	39
2025	KPK	Bannu	PV	140	6.61	8.12	0.47	32,666,090	39
2025	Punjab	Kalar Kahar	PV	140	6.31	8.10	0.47	32,902,232	39
2025	Punjab	Alipur	PV	140	6.25	8.09	0.47	33,138,487	39
2025	Punjab	Hasilpur	PV	140	6.10	8.08	0.46	33,369,358	39
2025	Punjab	Pindi Gheb	PV	140	6.08	8.06	0.46	33,600,722	39
2025	Punjab	Chakri	PV	140	6.08	8.05	0.46	33,833,754	39
2025	Punjab	Athran Hazari	PV	140	6.05	8.04	0.46	34,063,854	39
2025	Punjab	Muzaffargarh	PV	140	6.03	8.02	0.46	34,293,970	38
2025	KPK	Kohat	PV	140	6.03	8.01	0.46	34,524,286	38
2025	Punjab	Dajal	PV	70	5.97	8.00	0.46	34,644,685	38
2025	Punjab	Firoza	PV	70	5.92	8.00	0.46	34,767,161	38
2025	KPK	Kulachi	PV	140	5.91	7.98	0.46	34,998,202	38
2025	Punjab	Darya Khan	PV	140	5.87	7.97	0.46	35,224,130	38
2025	Punjab	Fort Abbas	PV	70	5.70	7.96	0.46	35,340,978	38
2025	KPK	Warsak	PV	72	5.55	7.95	0.46	35,460,338	38
2025	Punjab	Rangpur	PV	70	5.26	7.94	0.46	35,573,889	38
2025	Punjab	Lodhran	PV	42	5.22	7.94	0.46	35,644,819	38
2025	Punjab	Chunian	PV	39	4.91	7.93	0.46	35,707,619	38
2025	Punjab	Habib abad	PV	42	4.28	7.93	0.46	35,775,279	38
2030	Sindh	Jhimpir 30	Wind	500	9.73	8.02	0.47	37,738,615	38
2030	Balochistan	Chaghi 30	Wind	4,000	9.44	8.46	0.54	54,699,631	41
2030	Balochistan	Quetta 30	PV	180	9.10	8.47	0.54	55,117,232	41
2030	Punjab	Rojhan 30	PV	870	8.36	8.46	0.53	56,860,553	41
2030	Sindh	Nawabshah Solar Park	PV	520	8.16	8.46	0.52	57,865,363	41
2030	Sindh	Jhimpir 30	PV	250	7.86	8.45	0.52	58,360,779	41
2030	Sindh	Wahi Pandhi Dadu	PV	420	7.73	8.44	0.51	59,147,842	41
2030	Punjab	QA Solar Park Bahawalpur 30	PV	1,016	7.64	8.42	0.50	60,947,870	41
2030	Balochistan	Chaghi 30	PV	3,000	7.57	8.34	0.49	67,583,361	45
2030	Punjab	Rahim yar Khan	PV	560	7.12	8.32	0.48	68,557,966	45
2030	Punjab	DG Khan	PV	650	7.05	8.30	0.48	69,655,959	44
2030	KPK	DI Khan	PV	520	6.82	8.28	0.48	70,512,052	44
2030	Punjab	Jauharabad	PV	700	5.92	8.24	0.48	71,584,469	44

In order to remain within the original targets, in Scenario 3, the highest-cost sites of Scenario 2 were excluded to come back to the original 20 percent and 30 percent targets, thus using a smaller number of sites with more optimized sizing, i.e., 41 sites instead of 73. Again, due to year differentiation existing sites, the total row number is more than 41.

As a result, this study recommends tendering out the identified PPSs in the priority given in Table 3-9. If the tender results turn out to be unsatisfactory, rebidding may be done for the given PPS, or the PPS can be sidelined.

TABLE 3-9: KEY OUTPUT PARAMETERS FOR THE SELECTED POTENTIAL PROJECT SITES (PPSs) USING OPTIMAL SIZING (SCENARIO 3)

Year	Province	Location	Technology	MW Selected	Spot Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	MWh VRE Production (cumulative)	Portfolio Capital Factor Grid (%)
2019	Sindh	Sindh existing	PV	100			0.27	191,649	27
2019	Sindh	Sindh existing	Wind	1,235			0.57	4,066,061	35
2019	Punjab	Punjab existing	PV	400			0.61	4,978,497	30
2022	Sindh	Sindh 22	Wind	860	9.99	7.48	0.60	8,502,258	35
2022	Sindh	Sindh 22	PV	480	8.77	7.61	0.60	9,465,375	35
2022	Punjab	Punjab 22	PV	300	7.59	7.61	0.60	10,001,724	35
2023	Balochistan	Kuchlak	PV	200	9.74	7.71	0.59	10,485,461	35
2023	Balochistan	Panjgur	PV	254	9.58	7.81	0.58	11,085,162	35
2023	Sindh	Jhimpir 23	Wind	450	9.30	8.01	0.59	12,858,388	36
2023	Balochistan	Chinali	PV	132	9.29	8.04	0.59	13,173,888	36
2023	Balochistan	Khuzdar	PV	244	9.24	8.09	0.58	13,724,835	36
2023	Balochistan	Muslim Bagh	PV	132	9.12	8.11	0.57	14,032,469	36
2023	Balochistan	Khanozai	PV	120	9.11	8.13	0.57	14,315,144	36
2023	Balochistan	Drazanda	PV	132	9.10	8.15	0.56	14,621,989	36
2023	Balochistan	Mastung	PV	120	8.87	8.17	0.56	14,895,459	36
2023	Sindh	Jhimpir 23	PV	200	8.27	8.17	0.55	15,293,946	39
2023	Punjab	Rojhan 23	PV	290	8.25	8.17	0.54	15,875,830	39
2023	Balochistan	Hub	PV	210	7.86	8.17	0.53	16,285,724	39
2023	Sindh	Nara	PV	60	7.74	8.16	0.53	16,408,912	38
2023	Balochistan	Mach	PV	132	7.72	8.16	0.52	16,670,516	38
2023	Balochistan	Bostan	PV	130	7.69	8.15	0.52	16,930,937	38
2023	Punjab	QA Solar Bahawalpur	PV	650	7.60	8.11	0.51	18,089,618	38
2023	Punjab	Chistian	PV	390	7.58	8.09	0.50	18,782,855	37
2023	Sindh	Sanghar (Deh 22 Jamrao)	PV	140	7.50	8.09	0.49	19,053,498	37
2023	Sindh	Mehrabpur	PV	140	7.37	8.08	0.49	19,318,375	37
2023	Sindh	Jacobabad	PV	140	7.35	8.07	0.49	19,580,722	37
2023	Sindh	Sukkur	PV	140	7.33	8.06	0.49	19,844,175	37
2023	Sindh	Rato Dero	PV	140	7.31	8.05	0.48	20,104,772	37
2023	Sindh	Shikarpur	PV	140	7.07	8.03	0.48	20,358,335	37
2023	Sindh	Manjhand 23	PV	65	6.18	8.02	0.48	20,487,648	37
2025	Balochistan	Chaghi 25	Wind	500	9.85	8.20	0.50	22,639,148	38

TABLE 3-9: *CONTINUED*

Year	Province	Location	Technology	MW Selected	Spot Financial Attractiveness	Portfolio Financial Attractiveness	Portfolio Load Correlation	MWh VRE Production (cumulative)	Portfolio Capital Factor Grid (%)
2025	Sindh	Jhimpir 25	Wind	500	9.70	8.32	0.52	24,602,484	39
2025	Balochistan	Kalaat	PV	120	9.08	8.32	0.51	24,884,167	39
2025	Balochistan	Mangochar	PV	120	9.05	8.33	0.51	25,165,757	39
2025	Balochistan	Hernai	PV	120	8.92	8.34	0.51	25,441,490	39
2025	Balochistan	Loralai	PV	50	8.54	8.34	0.51	25,554,626	38
2025	Balochistan	Musafirpur	PV	50	8.53	8.34	0.51	25,667,280	38
2025	Sindh	Manjhand 25	PV	500	8.33	8.34	0.50	26,662,472	38
2025	Balochistan	Chaghi 25	PV	250	8.23	8.34	0.49	27,230,612	39
2025	Sindh	Warah	PV	130	7.92	8.33	0.49	27,503,262	39
2025	Sindh	Jhimpir 25	PV	250	7.85	8.33	0.49	27,998,679	40
2025	Sindh	Gharo	PV	120	7.64	8.32	0.48	28,226,849	40
2025	Punjab	QA Solar Park Bahawalpur 25	PV	390	7.60	8.30	0.48	28,922,057	40
2025	Sindh	Gharo	Wind	210	7.48	8.28	0.49	29,595,933	40
2025	Sindh	Rohri	PV	140	7.41	8.28	0.48	29,859,100	40
2025	Sindh	Khipro	PV	140	7.40	8.27	0.48	30,126,178	40
2025	Sindh	Umerkot	PV	140	7.32	8.26	0.48	30,394,713	40
2025	Sindh	Mehar-Dadu line (Patt)	PV	140	7.23	8.25	0.48	30,656,414	40
2025	Sindh	Padidan	PV	140	7.08	8.24	0.48	30,924,231	39
2025	Sindh	Moro	PV	65	7.01	8.24	0.47	31,048,552	39
2025	KPK	Bannu	PV	140	6.61	8.22	0.47	31,292,181	39
2025	KPK	Kohat	PV	140	6.03	8.21	0.47	31,522,497	39
2030	Sindh	Jhimpir 30	Wind	500	9.73	8.30	0.49	33,485,833	40
2030	Balochistan	Chaghi 30	Wind	4,000	9.44	8.68	0.56	50,446,849	42
2030	Balochistan	Quetta 30	PV	180	9.10	8.69	0.56	50,864,451	42
2030	Sindh	Jhimpir 30+	Wind	2,000	8.95	8.72	0.59	58,717,795	42
2030	Punjab	Rojhan 30	PV	870	8.36	8.71	0.58	60,461,116	42
2030	Sindh	Nawabshah Solar Park	PV	520	8.16	8.70	0.57	61,465,926	42
2030	Sindh	Jhimpir 30	PV	250	7.86	8.70	0.57	61,961,342	42
2030	Balochistan	Chaghi 30	PV	3,000	7.57	8.59	0.54	68,596,834	47

3.5 ADJUSTMENT OF EXISTING LOIs

Future RE investments in Pakistan will be legislated by the 2019 RE policy and will be based on reverse bidding. However, the RE projects which are already in the pipeline, developed through the RE 2006 policy, that have not achieved COD, have been divided into three categories. The first category is projects which have secured a Letter of Intent (LOI), an official tariff, and a Letter of Support (LOS); the second category is on projects which have secured a LOI and an official tariff only; and the third category is on projects which have secured a LOI only.

It is assumed for this report that the projects under categories I and II will be completed under the previous RE 2006 policy, but in some cases their tariff might be revised depending upon their progress and deadline. Hence, in the present locational study, these plants have been accounted for as "committed," which will be completed soon, with their capacity reflected in the 20 percent VRE target by 2025. Category I and II plants, expected to be commissioned by 2022, have been cumulatively added for each province, named as Punjab 22 and Sindh 22, along with KE confirmed plants expected to be completed before 2023. The list of VRE plants considered confirmed is in the detailed report of Task 3 (Annex A.3).

However, for category III plants, it is assumed that they will be allowed to move ahead only if they are successful in the competitive bidding process. Thus, category III plants with a proposed land and grid study, such as the solar park in Bahawalpur and wind projects in the Jhimpir wind corridor, have supposedly been included in the VRE locations identified in this study. However, not all the plants in category III could be accounted for, as data and status of some of them could not be verified.

3.6 ADDITIONAL SITES

Some additional sites have been proposed over and above Scenario 1 (government/NTDC target). Scenario 1 is based on an NTDC load forecast and grid study analysis accordingly (Chapter 2), to show grid stability and dispatch under it. However, if the load is higher than the estimate or a province or region is more active, further large-scale VRE sites have been selected and suggested, such as QA Solar Bahawalpur 700 MWp additional to the Scenario 1 numbers, Quetta (year30+, 2,400 MWp), and Jhimpir (year 30+, 2,000 MW wind). **Analysis of these large-scale sites is given in Annex A.3 for Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan.**

3.7 CSP AS ALTERNATIVE TECHNOLOGY IN BALOCHISTAN

CSP (Concentrated Solar Power) is a solar technology which is alternative to PV, where the heat of the sun irradiation is utilized to heat up a medium, and then used to run a steam turbine based on the collected heat. Although CSP has generally higher specific costs than PV, it comes with the additional advantage of easy storage, making it an attractive case for the grid operator and utilities, as its generation dispatch is more plannable and stable. Its site requirements are slightly different than for PV, as it requires a high direct normal irradiation (DNI), whereas PV requires high global horizontal irradiance (GHI). Therefore, ideal sites differ slightly.

In the case of Pakistan, Balochistan is almost the only province which is favorable for CSP. The area around Quetta specifically has very good DNI values and also free grid capacities, such as at the suggested sites of Kuchlak (200 MW) and Khanozai (100 MW).

If CSP is added to the overall portfolio, these two sites (and the other sites around Quetta) are therefore recommended to be the first to be tendered out for this technology. More sites for CSP can later be identified if needed, mostly in Balochistan.

3.8 RECOMMENDATION

The recommendation of this study is to tender out the identified POAs in the priority given in Table 3-9.

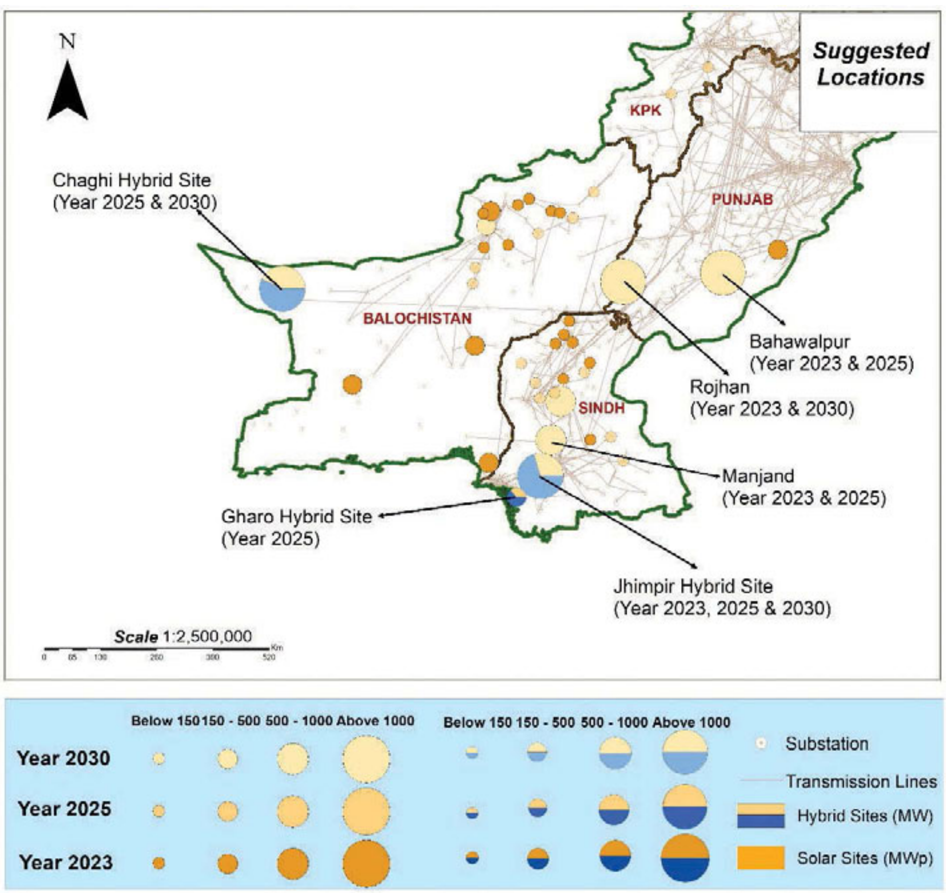
The recommended portfolio has been drawn based on the financial attractiveness of the prospective sites and required CAPEX. The volatility and correlation with the demand profile are reported as secondary parameters.

If the tender results turn out to be unsatisfactory, rebidding or sidelining may be done for the given POA thus proceeding to the next POAs in the ranking.

Specific recommendations from this study are as follows:

1. To **tender out the sites in the sequence as per the ranking given in Annex A.3 for Task 3: Shortlisting and Ranking of Solar and Wind Opportunities for Pakistan.** Figure 3-13 shows the suggested sites again, sorted by year of possible implementation. The potential project sites should be tendered for the lowest PPA price for 25 years, with an option for the GoP to take over the plant thereafter.
2. Before the bidding process, **further specific site details should be provided** by the government, which should at least be at a similar level of detail as in the Annex 4 report of this study (10 potential

FIGURE 3-13: PROPOSED SITES FOR 2023 (DARK ORANGE), 2025 (LIGHT ORANGE), AND 2030 (LIGHT YELLOW/BLUE)



project sites in Sindh). Most importantly, government owned land or an expected land lease should be secured in order to avoid a prohibitive cost of land to the bidders.

3. More recommendations on the tendering process will be provided in a different study currently underway by the World Bank.
4. The **PPA with winning bidders may be time sensitive,** e.g., have a higher value during the day than at night according to the value of electricity, to incentivize a load curve fit. However, as such a formula might make the financing more complex, this should be considered.
5. To speed up the process, available **government-owned land close to the Potential Project Sites (PPSs) selected under Scenario 3 should be identified and made available** for potential bidders. Other potential sites without any earmarked government land might also be tendered out; however, a strict maximum price benchmark for the land lease rate should be set in that case.
6. The tender should be **technology agnostic** to allow the bidders to determine the best technology or hybrid at the optimal DC-to-AC ratio (installed solar nameplate capacity versus maximum grid capacity).
7. It could be made mandatory that the bidders guarantee a **minimum (initial) grid utilization factor** of the available grid capacity set by the GoP. A higher grid utilization factor proposed by bidders would be permitted if grid constraints are met.
8. **Dynamic Line Rating (DLR)** would enable higher output at peak times for VRE plants and should be considered. For every potential project site, a dynamic grid capacity could then be used, i.e., for 2–3 hours during the daytime some relaxation may be given by the authorities to maximize the grid capacity factor and evacuate extra energy. This would increase the actual CF and reduce the cost per kWh utilizing economies of scale.

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ANNEXES

Annexes 1, 2, 3, and 4 are published separately on the World Bank website. These are:

ANNEX 1: RENEWABLE ENERGY ZONING STUDY FOR PAKISTAN (DETAILED REPORT)

ANNEX 2: GRID INTEGRATION ANALYSIS FOR POTENTIAL VRE IN PAKISTAN (DETAILED REPORT)

ANNEX 3: SHORTLISTING AND RANKING OF SOLAR AND WIND OPPORTUNITIES FOR PAKISTAN (DETAILED REPORT)

ANNEX 4: SUPPLEMENTAL ANALYSIS OF SITES IN SINDH

SOLAR MAP (INTERACTIVE PDF)

WIND MAP (INTERACTIVE PDF)

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