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Balochistan Renewable Energy Development Study

Pakistan Sustainable Energy Series

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CIF CLIMATE INVESTMENT FUNDS

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Images and Photography

Front and back Cover: Noor Ouarzazate Solar Power Complex. Morocco. Photo: Oliver Knight / World Bank.

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Abbreviations and Acronyms

/a	per annum
AC	Alternating Current
AEDB	Alternative Energy Development Board (now PPIB)
BECL	Balochistan Energy Company Limited
BED	Balochistan Energy Department
BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CASA	Central Asia-South Asia
CF	Capacity Factor
CPPA	Central Power Purchasing Agency
CSP	Concentrated Solar Power
CTBCM	Competitive Trading Bilateral Contracts Market
DC	Direct Current
DISCO	Distribution Company
DNI	Direct Normal Irradiance
DPV	Distributed (Photovoltaic) Solar
EPA	Energy Purchase Agreement
EPC	Engineering, Procurement, Construction
GENCO	Generation Company
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GW	Gigawatt
GWh	Gigawatt hour
HFO	Heavy Fuel Oil
HPP	Hydroelectric Power Plant
HVDC	High Voltage Direct Current
IA	Implementation Agreement
IGCEP	Indicative Generation Capacity Expansion Plan
IPP	Independent Power Producer
KE	Karachi Electric (Distribution Company)

kT	kilotons
LCOE	Levelized Cost Of Electricity
LCOH	Levelized Cost Of Hydrogen
MoE	Ministry of Energy (Power Division)
MPC	Marginal propensity to Consume
MW	Megawatt
MWh	Megawatt hour
MWp	Megawatt Peak
NEPRA	National Electric Power Regulatory Authority
NPV	Net Present Value
NTDC	National Transmission and Dispatch Company
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PPA	Power Purchase Agreement
PPIB	Private Power & Infrastructure Board
PSS/E	Power System Simulator for Engineers (software for simulation of the electric grid)
PV	Photovoltaic
QESCO	Quetta Electricity Supply Company
RE	Renewable Energy
SIL	Surge Impedance Loading
TIP	Transmission Investment Plan
TSEP	Transmission System Enhancement Plan
VRE	Variable Renewable Energy
WACC	Weighted Average Cost of Capital
WB	World Bank
WTG	Wind Turbine Generator

Executive Summary

The Balochistan Renewable Energy Development Study is a continuation of the World Bank's previous works on analyzing Pakistan's variable renewable energy (VRE) potential, mainly the VRE locational study report, which was published in 2021. This study crystallizes the previous results, going into greater depth using the latest data and information for the province of Balochistan where the RE potential is greater and at the lowest cost than in any other province, offering the potential to transform the province into a net exporter of energy within the country, and thereby facilitate its economic and social development.

The objective of this study is to generate interest in and political commitment to the strategic development of utility-scale solar and wind power in Balochistan to help meet Pakistan's ambitious RE targets for the power sector and support the broader transition necessary to achieve "affordable, reliable, sustainable, and modern energy for all." This study is intended to support federal and provincial policy development, investment planning, and project concept preparation. VRE could drastically reduce the burden on Pakistan's economy imposed by the high cost of importing fuels—oil, gas, or coal—and in Balochistan, the VRE costs are the least in Pakistan.

The study has been carried out by a team of experts over a period of 13 months in close consultation with the former Alternative Energy Development Board (AEDB) (merged with the Private Power Infrastructure Board (PPIB) in May 2023), as the primary counterpart and in collaboration with all the key federal and provincial organizations. The study incorporates the views of various stakeholders, including local farmers, the provincial government, the federal government, potential developers, the private sector, investors and financial institutions, electricity companies, and environmentalists. These views were taken on board throughout the entire process, which consisted of two stakeholder workshops and regular technical-level meetings.

In this study, different VRE options are developed and evaluated in a quantitative supply–demand-based cost analysis for short- (2028) and medium-term (2033) development. Potential roadblocks and catalysts have been analyzed and recommendations formulated accordingly. The 2022–2032 load forecast for Balochistan from the regional electricity company (Quetta Electricity Supply Company: QESCO) and 2022 data for Pakistan from the Indicative Generation Capacity Expansion Plan (IGCEP) serve as reference for modeling the energy demand and supply in this study. Additionally, the study uses the latest grid model available from the National Transmission and Dispatch Company (NTDC), plus data on existing power plants and distribution companies, cost of power, and line losses from the National Electric Power Regulatory Authority's (NEPRA) 2022 State of Industry Report.

Main Findings:

The following is a summary of the main findings and conclusions based on the different evaluations developed in this study. The detailed annexes are published separately, to facilitate a comprehensive understanding of the results, implications, and recommendations of this study.

Balochistan has enormous VRE potential which can electrify the province and help Pakistan in achieving the 30 percent VRE target while saving significant GHG emissions.

Balochistan offers an impressive resource potential for economically viable solar and wind power generation, both of which are mostly untapped so far. With a Photovoltaic (PV) potential ranging from 2,000 to 2,500 kWh/m^2, Balochistan emerges as one of the world's most resource-rich regions. PV power in Balochistan can achieve grid utilization factors up to 35 percent, and its supply profile correlates positively with the demand profile. Additionally, excellent available Direct Normal Irradiation (DNI) of up to 2,500 kWh/m^2 per year in some areas of Balochistan offers great opportunities for Concentrated Solar Power (CSP). Furthermore, Balochistan has the best spots for wind power within Pakistan in the remote areas of Chagai and Panjgur, with average wind speeds of up to 10 m/s at a height of 100m, corresponding to a 15 GW power generation potential capacity at a highly competitive cost from clean energy resources.

Table ES1: Approximate cost breakdown

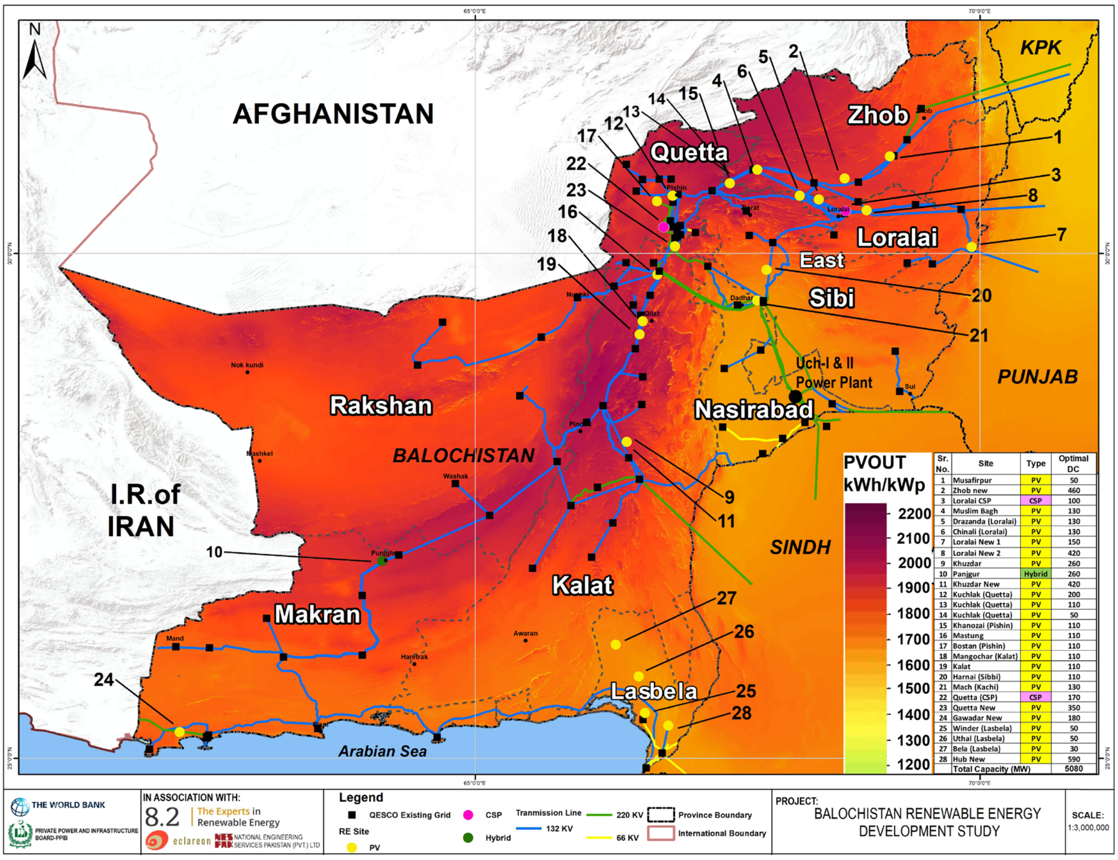
	Capacity PV	Sum of PPA x Capacity	Weighted average PPA	Weighted average PPA
Unit	MWp	Cts	Cts/MW	
Balochistan	2,516	11,836	4.70	4.70
KPK	280	1,740	6.22	
Punjab	1,720	9,266	5.39	5.47
Sindh	2,930	15,946	5.44	
Total	7,446	38,789	5.21	

Source: VRE locational study (World Bank,t 2021)

Roughly 5 GW of short-term opportunity in 28 sites for different types of technology have been identified—based on the long list of priority sites identified by the VRE Locational Study, exploring the grid slots and land availability in more depth and analyzing them further to achieve the most competitive generation from VRE. This significant potential capacity is the "low-hanging fruit" opportunity, which can be unlocked in the short term (2028) by utilizing the current grid infrastructure.

The analysis considered the expected energy yield, installation cost (including grid connection), and expected price of electricity for the identified capacity. The output of this exercise is shown below as potential short-term utility-scale projects overlaid on a PV energy output map, in line with the 2028 National Transmission System Expansion Plan (TSEP).

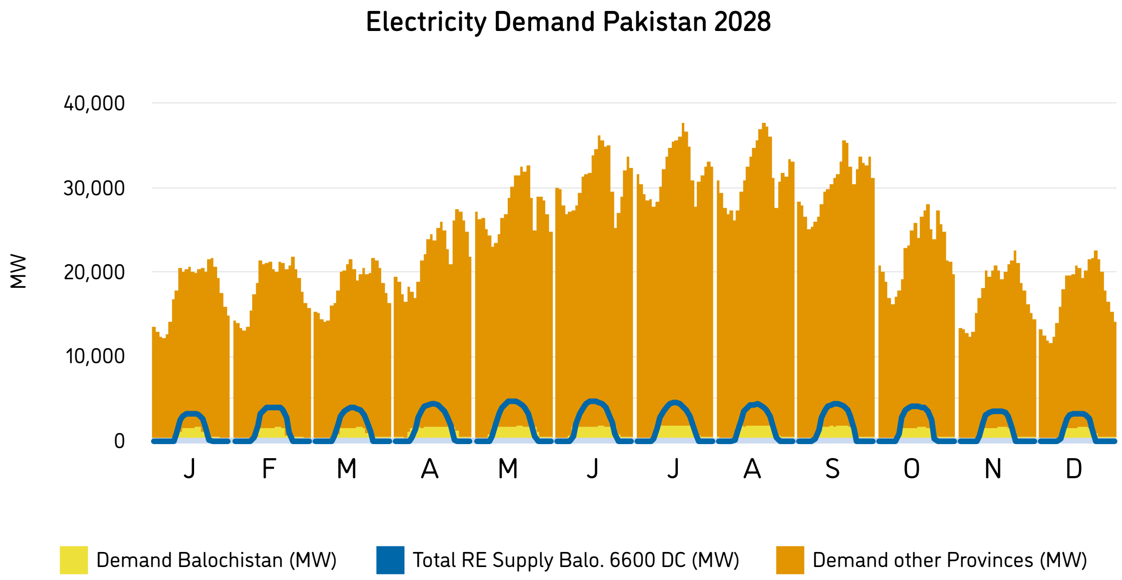
Figure ES1: Proposed utility-scale project sites for 2028



The expected PPA rates under current cost framework and condition of the sector are between US$0.042 and US$0.057/kWh for these identified sites.

Implementing of identified VRE by 2028 would not only help Balochistan transition fully toward clean energy—as the VRE potential surpasses the Balochistan demand in 2028—but also create an opportunity where competitive low-cost RE energy becomes available for other provinces.

Figure ES2: 2028 expected demand under IGCEP 2022 and simulated VRE production in Balochistan



In addition, there is a potential for 1.7 GWp Distributed PV to solarize about 28,000 grid-connected tube wells operated by farmers, the main electricity consumer in Balochistan. Installation of DPV would not only free up an additional capacity in the grid for further VRE installation but when combined with the investment in efficient motors and pumps; it would dramatically reduce the electricity losses in this segment. In other words, it would improve the electricity company's financial stability by reducing the approximately US$500 million annual losses by 2028, contributing to reducing the circular debt in the sector.

By co-locating solar and wind capacity, more reliable, least-cost energy options will be available in the long run—at a higher generation capacity factor than comparable hydropower plants.

Western Balochistan possesses significant potential for wind and solar PV electricity co-generation. This area's vast available space further enhances its potential for generating green energy at low costs, where up to 9 GW of solar and wind could be developed in stages as a large hybrid park with a higher capacity factor than comparable hydropower projects at competitive costs ranging from US$0.065 to US$0.082/kWh. Enhancing the grid capacity and expansion for developing VRE opportunities would reduce the country's dependence on water availability for hydropower generation. It also will develop Balochistan's economy and in the longer run, will reduce the cost of electricity for other provinces by more than US$1 billion.

Considering new investments, including new high-voltage transmission capacity, would enable the country to untap the huge resource potential of Balochistan in the long term.

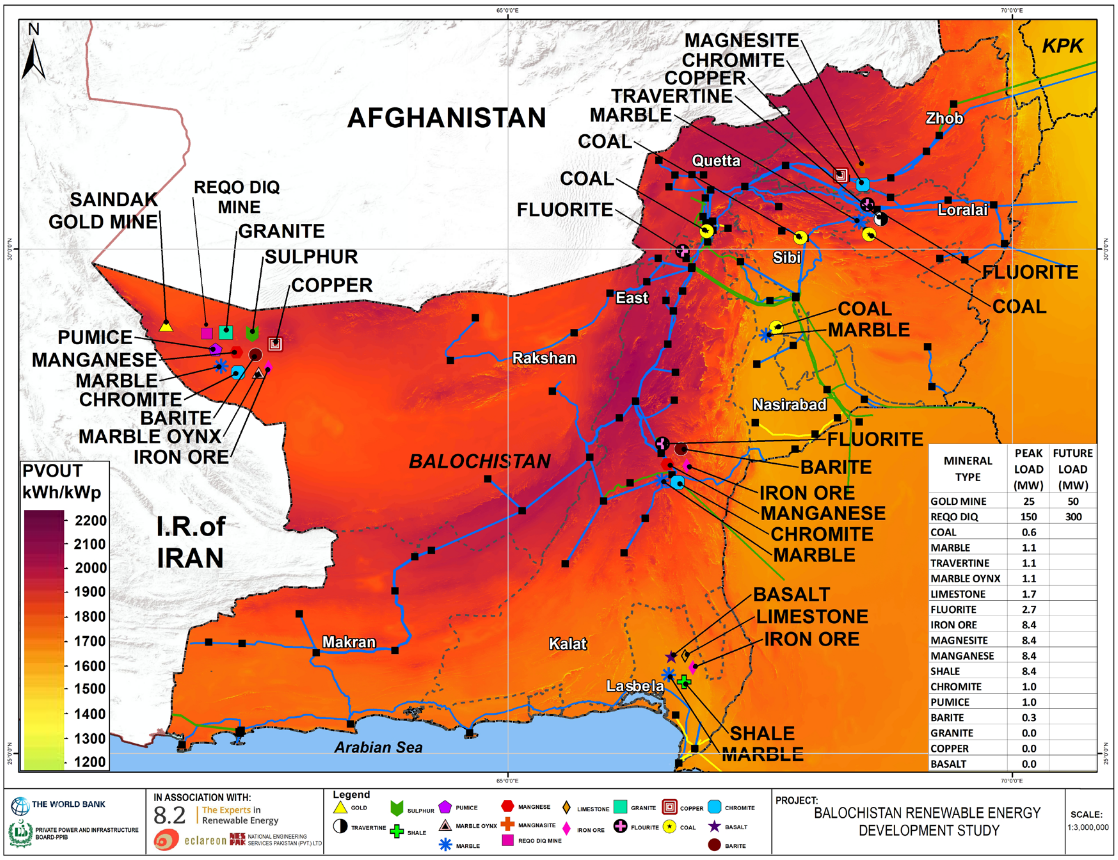
For the capacity additions beyond 5 GW, the requirement for an HVDC transmission line to evacuate the electricity generated in remote areas of GW opportunities and deliver it to the rest of Pakistan's grid is imminent. This would allow the integration of one or more GW hybrid parks of wind and PV with a grid utilization factor of approximately 60 percent which as mentioned is comparable to large hydropower projects.

For the proposed longer-term solution, with only 17.7 percent loading of a 4 GW High Voltage Direct Current (HVDC) transmission line, the costs are comparable to larger hydropower project opportunities, offering significant cost savings of US$0.071 vs. US$0.08 for hydro. At full utilization, boasting a high -capacity factor (around 60 percent), the cost of supply, including grid connection, would fall below US$0.065/kWh.

Balochistan's major industry, mining, would benefit from an environmentally friendly and cheap electricity supply that replaces the expensive, high carbon-emitting fossil fuel resources and drives the industry toward decarbonization.

Mining operations are a large VRE demand for consideration. The existing 63 MW energy need from mining is estimated to grow to 226 MW by 2028 when planned mining operations, including the potential contingencies, are on board. A significant cost advantage (30–60 percent) compared to heavy fuel oil (HFO) or diesel is determined by analyzing the feasibility and financial advantage of VRE as a fuel-saving instrument for existing and planned mining operations. The two largest mining ventures (Saindak and Reko Diq) alone could reduce their cost of electricity by 50 percent with some 500 MW of solar and wind while at the same time developing the region of Chagai, an area with the best wind and PV potential, not only nationally but even at a global level. Such development also could be built out in stages into a multi-GW park. In the medium term, the energy demands of certain mining operations, such as those anticipated for Reiko Diq's initial phase (150MW), are projected to double.

Figure ES3: Mining areas and PV resource

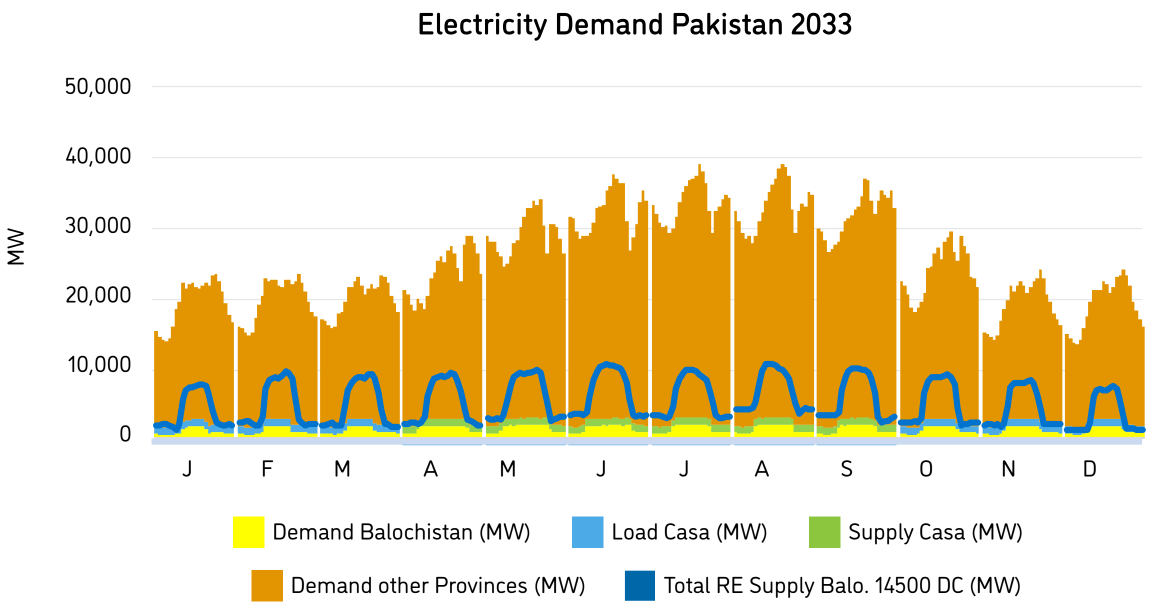


As most mines are located in remote areas without access to the public grid, this power supply opportunity for mining sites is to be considered separately from the on-grid VRE potential. PV and wind, possibly in combination with CSP, along with a battery energy storage system (BESS) as a backup, is a perfect off-grid opportunity for every mine in the province.

Realizing VRE opportunities in Balochistan will reduce Pakistan's need for electricity imports.

A longer-term VRE development in Balochistan will be very beneficial for the region in particular and for Pakistan as a whole as any potential VRE surplus can be exported to other provinces— or internationally, which reduces the electricity import bill. The existing import connection lines can then be used for stabilizing the grid, exchanging electricity with other countries at a competitive price, and optimizing the annual supply mix. In the short term (2028), a surplus VRE supply may not be available for consistent export throughout the year, but there might be a seasonal opportunity for export (Reverse Power Flow) through the Central Asia-South Asia (CASA 1000) HVDC Transmission Line—soon available—to Central Asia (Uzbekistan, Kyrgyz Republic and potentially to Kazakhstan). In this Central Asia Regional Electricity Market (CAREM), countries have an electricity deficit in winter, and demand is growing. **It is noteworthy that countries in central Asia might be interested in supporting the GW-scale opportunity for their seasonal electricity demand deficit.**

Figure ES4: 2033 demand profile, including CASA export in winter



The study presents five case studies based on the analysis carried out for the identified short-term opportunities considering the expected energy yield, installation cost (including grid connection), and expected price of electricity:

Case Study 1 (2028): A 200 MW Utility-scale PV plant in Kuchlak, Quetta region;

Case Study 2 (2028): A 100 MW Utility-scale CSP in the North of Quetta or Kalat region;

Case Study 3 (2028): A 450 MW Hybrid RE Plant in REKO DIQ mining site;

Case Study 4 (2033): A 7–9 GW Hybrid RE Park in Western Balochistan, Chagai region; and

Case Study 5 (2028): A DPV implementation for Sira Qilla, Pishin supply feeder.

Significant socioeconomic benefits from VRE will contribute to GDP growth in Balochistan. While the direct financial benefit to the province may not be in the form of direct revenue due to the prevailing burden of circular debt borne by the government of Pakistan, the installation of VRE plants in Balochistan can bring several indirect economic benefits, including job creation, development profits, industrial cost reductions, reduced import dependency, potential electricity exports, improved agricultural practices (with better livelihoods for farmers) and increased local income. These factors can contribute to improved living standards, economic growth, and regional development. Installation of up to 14 GW of VRE is expected in the long term to raise Balochistan's GDP by some US$3 billion per year, up 30 percent on the present-day situation. More than 25,000 permanent jobs could be generated on the back of a thriving industrial base. Installing 1.3 GW of DPV in Balochistan alone would lead to GDP growth and a reduction of circular debt of approximately US$0.3 billion per year.

Low-cost green electricity can attract international investment in green hydrogen production.

With enormous wind and solar power potential and the very competitive VRE generation profile in Balochistan, Pakistan can offset the challenges for creating a hydrogen market within the country—including the challenging infrastructure environment in Balochistan and the long distance to green hydrogen markets such as the European Union. Crucially, such efforts will serve to shape a favorable financing landscape for the country.

Since Pakistan is a country that is severely affected by climate change, it might have a good chance to secure bilateral or multilateral financial and technical assistance from donor countries to assess and implement such a large infrastructure project under favorable terms. Electricity exported from Gwadar would further strengthen local industry and benefit development in both Balochistan and Pakistan.

Policy Recommendations and Proposed Next Steps

To unlock the identified potential, an active governmental role, political support, and strong decision-making at both the provincial and national levels are needed.

- At the federal level, the Pakistan government should set clear targets and clarify responsibilities among provincial and federal governmental entities for developing VRE projects. The federal government should strongly encourage the opportunities identified in the rolling planning activities for the national electricity supply.

  NTDC approval of the plants identified in this study would be required to start the planning, while the grid interconnection readiness can be checked in-house.

  For PPIB, the opportunity can be taken up for competitive bidding once the national competitive bidding process is finalized. To get the lowest cost with the highest line capacity factor, the bidding should focus on the maximum energy to be delivered into the grid (AC requirement) rather than a fixed DC size.
- At the provincial level, allocating land within a reasonable timeframe and building and supporting the local capacity of BECL is important. A dedicated project management based in the province, like BECL, is needed to ensure provincial political support, especially timely land allocation. The provincial management would need to decide to develop a pilot model for the implementation of VRE as a first step, facilitating tackling these issues.
- Additionally, BECL and the Department of Mining can further promote the use of VRE through the realization of a pilot project at a mining site, which could be a tremendous marketing opportunity for Balochistan. This should be facilitated at the highest level in the province.
- A DPV program also would need a dedicated impetus from the provincial leadership to address the technical and commercial issues related to tube wells. Provincial project management for implementing such solutions, and maximum support from the MoE Power Division to reduce the circular debt cycle, are needed.

Grid investment and preparation for future expansion are keys for utilizing the immediate potential VRE capacity and eventually growing beyond it.

The different development phases of longer-term opportunities of a GW-scale Park should be modeled for the IGCEP to understand the overall evaluation of the long-term national concept, including any seasonal export opportunity. Additionally, a comprehensive masterplan/feasibility study to determine location, bankable wind resources, and stagewise grid connections cost would be essential.

Additionally, the previously published VRE Locational Study (World Bank 2021) and VRE Integration and Planning Study (World Bank 2020) outline a series of investments, auxiliary measures and operational changes that need to be implemented at national level, with many of them required regardless of the addition of more solar and wind power plants to the grid.

Minimizing security risks through local acceptance:

Local acceptance and community engagement are critical factors for successfully realizing RE projects. This serves to mitigate the security risks. Conversely, if RE projects are realized without the prior engagement of local communities, a negative local perception of those projects is expected. Some guidelines include participatory processes that can lead to increased public acceptance.

- The implementation of infrastructure development projects can be facilitated through engagement with tribal leaders in Balochistan and through confidence-building measures, such as setting up education and health facilities.
- A utility-scale RE system in the neighborhood will only have positive effects, provided the system is not installed on disputed land and does not affect the local population's day-to-day life. The installation and O&M of the system has the potential to create temporary and permanent jobs. It is recommended and assumed that BECL and developer make an effort to offer unskilled jobs to the local population and train local people for permanent O&M and security jobs.

1. Introduction

1.1. Country and Sectoral Context

Pakistan is the most successful country in South Asia in terms of transforming GDP growth into poverty reduction, and also one of the most successful among lower middle-income countries. More than 32 million Pakistanis were relieved from poverty in the period 2001, with a headcount of 64.3 percent to 2015, when poverty had more than halved, falling to 24.3 percent. However, the country has been beset by recurrent macroeconomic crises and a poor record of human capital development. Over the past two decades, Pakistan has struggled to sustain growth, with short spells of faster growth regularly followed by a crisis. General macroeconomic instability has, therefore, given rise to repeated boom-bust economic cycles. As a result, on average, Pakistan's real per capita GDP growth rate between 2000 and 2018 was only 2.1 percent, substantially below the performance of other countries in the region. Pakistan has seen an average annual growth of 4.4 percent, lagging behind the South Asian average of 6.3 percent, alongside a per capita GDP of only US$1,798 in 2021–2022.

Over the past few decades, Pakistan has achieved outstanding development in connecting its population to the electric grid. The 2014 SEforAll Global Tracking Framework Report ranked Pakistan fourth in the world in terms of the number of people who gained access to electricity between 1990 and 2010 (approximately 91 million people received electrical services for the first time during this period).[1] However, in 2020, Pakistan was still among the top 20 countries with the largest access deficits (these countries are home to 76 percent of the entire global population living without access to electricity).[2]

The government of Pakistan plans to reduce the gap between electricity supply and demand by increasing its generation capacity by another 38 GW by 2028 and 64 GW by 2033. (IGCEP 2047). Pakistan has immense sources of renewable energy that it could harness for this plan. The solar resource potential is very high, especially in the southern and western parts of the country. According to the World Bank Global Photovoltaic Power Potential Study from 2020, utilizing just 0.071 percent of Pakistan's available area for solar photovoltaics would meet Pakistan's current total electricity demand.[3] The wind resource is also significant, especially in the southwest and southeast (Balochistan and Sindh). The Pakistan Alternative Renewable Energy Policy, which was approved in 2019, drew up the target of achieving 20 percent of power capacity from nonhydro renewable energy sources by 2025, and 30 percent by 2030. Additionally, the Indicative Generation Capacity Expansion Plan (IGCEP) 2021–2030 (which includes hydropower in a broader definition of renewable energy) sets a country goal for achieving 60 percent of electricity generation from renewable energy resources by 2030.

1.2 Study Context and Objective:

The World Bank is supporting Pakistan's energy sector through a multi-year Programmatic Advisory Services and Analytics (PASA) activity titled "Pakistan Sustainable Energy Program," (P169313) which complements and informs the World Bank's policy advice to the government of Pakistan, and its extensive energy sector lending portfolio. Under this program the World Bank has published three major studies on VRE that have helped inform the Alternative & Renewable Energy Policy 2019 (AEDB, 2019), the most recent version of the Indicative Generation Capacity Expansion Plan (IGCEP 2022) (NEPRA, 2022), and the federal government's policy on renewable energy more broadly. The three published studies are:

i. Variable Renewable Energy Integration & Planning Study (November 2020);[4]

ii. Variable Renewable Energy Locational Study (February 2021);[5]

iii. Variable Renewable Energy Competitive Bidding Study (May 2022).[6]

Building on the existing analysis by the World Bank, and in view of the enormous VRE potential in Balochistan, which can support the country in achieving the 30 percent VRE target by 2030, with several opportunities that can

1 World Bank and the International Energy Agency, 2014, *SEforAll Global Tracking Framework Report*

2 World Bank, the International Energy Agency, the International Renewable Energy Agency, the United Nations, and the World Health Organization, 2022, *Tracking SDG7: The Energy Progress Report 2022*

3 World Bank, 2020, *Solar Photovoltaic Power Potential by Country*.

4 World Bank. 2020. *Variable Renewable Energy Integration & Planning Study.* Pakistan Sustainable Energy Series. Washington, DC: World Bank.

5 World Bank. 2021. *Variable Renewable Energy Locational Study*. Pakistan Sustainable Energy Series. Washington, DC: World Bank.

6 World Bank. 2022. Variable Renewable Energy Competitive Bidding Study. Pakistan Sustainable Energy Series. Washington, DC: World Bank.

be implemented in the short-term (World Bank VRE Locational Study, 2021), the World Bank has been discussing future priorities with the Alternative Energy Development Board (AEDB), which is currently merged[7] with and known as Private Power and Infrastructure Board (PPIB), and has held several parallel discussions since early 2021 with the Energy Department of the government of Balochistan (Balochistan Energy Department, or BED). There is strong consensus that utility-scale RE development in Balochistan must be strategically pursued, and a .recognition that this will require both federal and provincial engagement, coordinated and led by AEDB

In support of this, the World Bank and AEDB agreed to carry out an initial study on renewable energy development in Balochistan. The objective of the study is to generate interest in and political commitment to the strategic development of utility-scale solar and wind power in Balochistan to help meet Pakistan's ambitious RE targets for the power sector and support the broader transition necessary to achieve affordable, reliable, sustainable, and modern energy for all. The study will support federal and provincial policy development, .investment planning, and project concept preparation

This study incorporates the views of various stakeholders, including local farmers, the provincial government, the federal government, potential developers, financial institutions, electricity companies, and environmentalists. The Main Report for this study is published separately and is accompanied by eight annexes that provide further details on the analysis as follows:

- Annex A: CSP technology
- Annex B: Socioeconomic Impacts
- Annex C: Hydrogen Model
- Annex D: Financial and Economic Model
- Annex E: (Separate Consultants Report)[8] Detailed Analysis of Utility-Scale Opportunities
- Annex F: (Separate Consultants Report) Detailed Analysis of Hybrid RE Opportunity at Reko Diq Mining Site
- Annex G: (Separate Consultants Report) Detailed Analysis of GW Park
- Annex H: (Separate Consultants Report) Detailed Analysis of DPV

2. Methodology and Assumptions

2.1 General

Building on existing analysis by the World Bank (VRE Locational Study 2021) and other organizations, the study investigates and prepares recommendations for developing utility-scale solar and wind power in Balochistan. It covers the period up to 2030 and sets the stage for continued scale-up to 2040 and beyond. The study is based on likely scenarios for overall renewable energy capacity additions in Pakistan, including stretch scenarios that require additional solar and wind capacity above that stated in the latest version of IGCEP. It crystallizes the previous results in greater depth using the latest detailed data and information. Different VRE options are developed and evaluated in a Balochistan supply–demand analysis for 2028 and 2033 for short- and medium-term development: potential roadblocks and catalysts have been analyzed, and recommendations formulated accordingly.

The study determines costs for various VRE options in Balochistan using quantitative techno-economic analysis. Local, provincial, and national electricity demand are used to determine the upper ceiling for potential VRE electricity. This ceiling is reduced by grid constraints and other indigenous resources already installed or planned, mostly hydropower. It is assumed that all VRE options will be financed by Independent Power Producers (IPPs) so that the cost of conventional electricity supply (base cases) can be directly compared with the levelized cost of the

7 In May 2023, the AEDB was merged with PPIB upon declaration of the Private Power and Infrastructure Board (Amendment) Act, 2023. The Alternative Energy Development Board Act, 2010 (Act XIV of 2010) has since been repealed.
8 Consultant reports can be found in 8.2 Renewable Energy Experts website.

VRE options. The annual savings in USD that result from using VRE installed in Balochistan are segregated into savings for Balochistan or for all other provinces of Pakistan. Additional value generation is included in the form of job creation and its economic implications. For more details on the quantitative model please refer to Annex D: Financial and Economic Model.

2.1.1 Assumptions and Inputs

The input data has been extracted from the following studies:

- VRE Locational Study (World Bank, 2021), which analyzes the utility-scale VRE potential of Pakistan;
- Quetta Electricity Supply Company (QESCO) market forecast (QESCO, 2021), which estimates the expected electricity demand in Balochistan;
- National Electric Power Regulatory Authority (NEPRA) State of Industry Report (NEPRA, 2022), which provides background information on existing power plants and distribution companies, cost of power, line losses, and so forth;
- Indicative Generation Capacity Expansion Plan 2022 (IGCEP 2022) (NEPRA, 2022), which is the result of the National Transmission and Despatch Company's (NTDC) cost optimization plan for electricity generation for Pakistan from 2022 to 2031;
- Medium Term Load Forecast 2022–2032 by QESCO (QESCO, 2021);
- Transmission System Expansion Plan (TSEP) 2026–2027 (NTDC 2022) as the basis for the grid and evacuation options and restrictions;
- Renewable Energy Jobs and Sector Skills Mapping for Pakistan (World Bank, 2022) for assessing the impact of various VRE expansion scenarios on potential direct and indirect jobs created;
- NTDC Feasibility Study on Solarizing Tube Wells (NESPAK, 8p2, 2020), which analyzes the potential, value, and cost of distributed solar (DPV) for grid-connected tube wells in Balochistan; and
- Barrick Gold plans for Reko Diq as background for direct electricity needs for the planned mining operations and as a hub for a wider local development.

2.1.2 Stakeholder Involvement

All national and provincial stakeholders such as the PPIB, NTDC, NEPRA, Central Power Purchasing Agency (CPPA), and BED, including the Balochistan Energy Company Limited (BECL), and QESCO, were consulted at the start of the study. The Ministry of Energy has nominated BECL as the focal point for implementing RE projects in the province.

During discussions, the main query from stakeholders was related to the utilization of Balochistan's VRE resources. The solar and wind potential of Balochistan has already been identified in the World Bank VRE Locational Study (2021). The main concern for NEPRA and CPPA was that under the National Energy Policy 2021 the least-cost generation plants should be given priority. However, for large-scale grid reinforcements, the cost should be included in the plant cost. The study goes to considerable lengths to address and highlight the concerns of all stakeholders.

2.1.3 Supply–Demand Modeling

A quantitative supply–demand model has been outlined to evaluate the lowest-cost option of VRE generation from Balochistan based on hourly data to account for variability in the VRE generation portfolio. The maximum feasible utility-scale VRE capacity from Balochistan at any simulated hour was defined as:

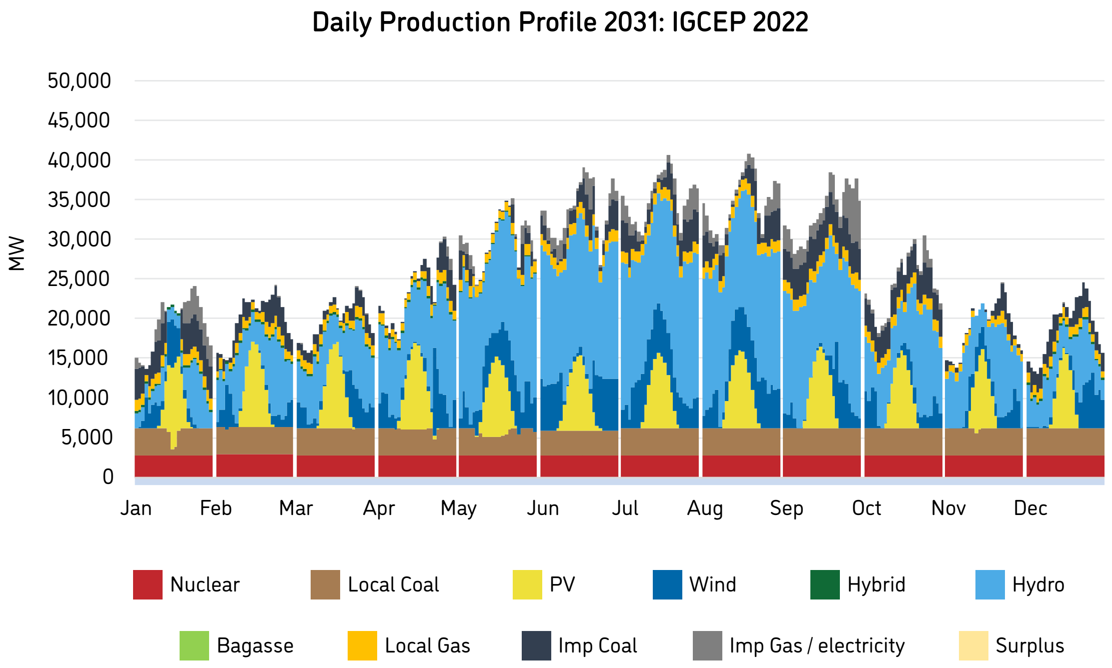
Export Capacity+Local Consumption-Distributed Generation =max VRE Capacity

The sources of demand were the QESCO load forecast for 2022–2032 (QESCO, 2021) for Balochistan and the IGCEP 2022 for Pakistan (NEPRA, 2022). The IGCEP 2022 provides demand data in hourly resolution for the whole country. In the IGCEP, the hourly resolution is condensed for a typical day per month resulting in 288 values per annum.

The selected reference year for this study is 2028, as per the latest grid model available from NTDC (TSEP 2022), for the short-term VRE options. For longer-term analysis, 2033 has been used as a reference year from the same TSEP 2022. The demand data for 2033 has been extrapolated from the available forecast up to 2032.

The figure below depicts Pakistan's load profile in 2028 using 288 hourly values [9] and includes VRE generation for the IGCEP base case in the form of solar and wind.

Figure 2.1: Pakistan load and production profile by technology

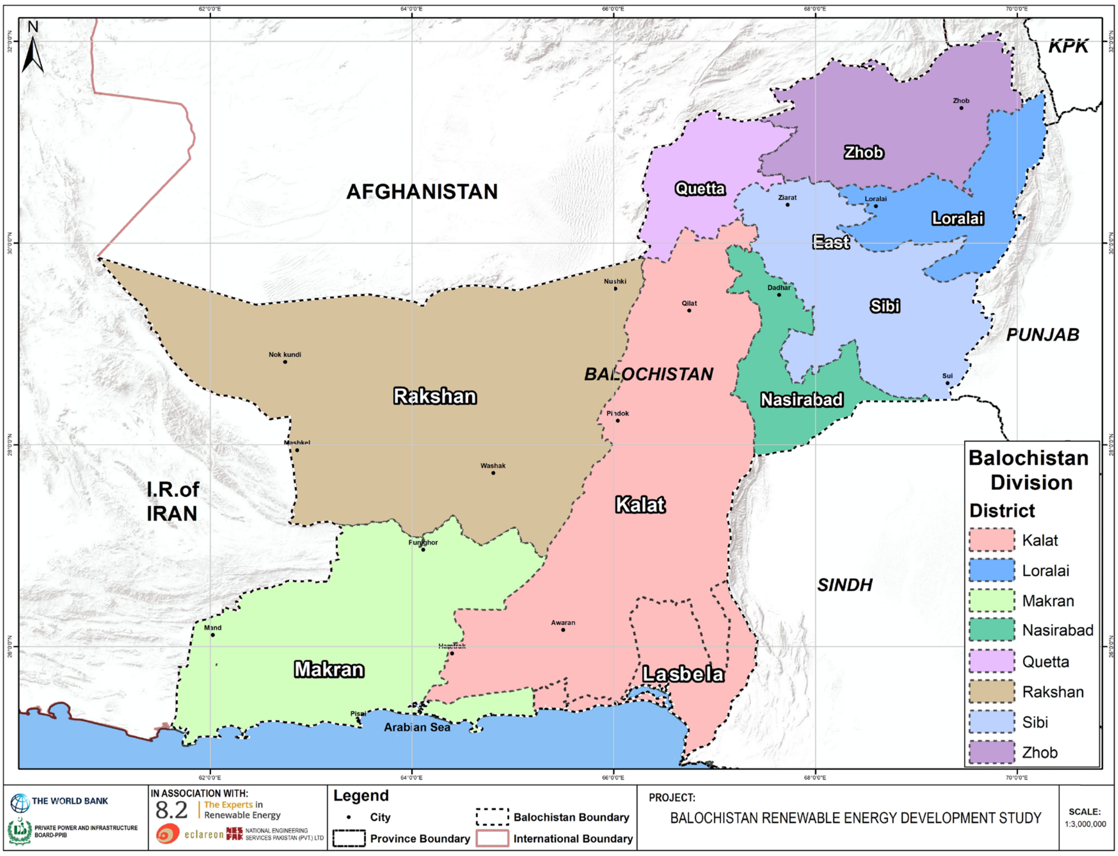


Data source: (NEPRA, 2022)

The QESCO load forecast provided monthly and peak consumption data for customer groups in different districts and regions.

9 One typical day per month (24 x 12 = 288).

Figure 2.2: Divisions of Balochistan



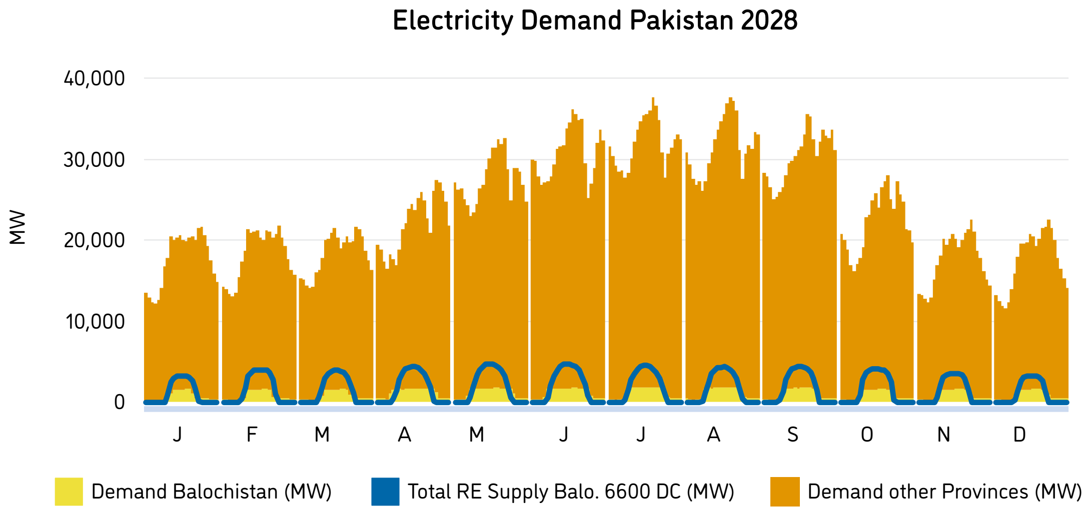
The regional demand forecast from QESCO was aggregated on a divisional level for Rakshan, Makran, Kalat, Quetta, and the eastern divisions as they are very similar in nature. The available monthly demand was distributed hourly for a typical demand picture in (rural) Pakistan to correspond with the requisite 288 hourly data points extracted from the IGCEP 2022. As most of the demand derives from agriculture tube wells in Balochistan, the irrigation demand analysis from the NTDC Solar Tube Well Feasibility Study (NESPAK, 8p2, 2020) based on 250 sites all over Balochistan was used for modeling. Since the demands for irrigation are not time-sensitive, it is assumed that demand peaks around midday.[10]

The potential electricity supply from VRE in this study was simulated for every project opportunity for all 8,760 hours in a year. To match the energy yield with demand and the IGCEP 2022 planning methodology, the simulated energy output was condensed to 288 hours by taking hourly averages for a typical day in a month. For the potential VRE supply, results of the VRE locational study data were reviewed, updated cost assumption adopted, and new locations added according to the 2028 grid model and available export capacity for the rest of Pakistan. In the model developed, any electricity not consumed within the province would be exported to other provinces of Pakistan. The impact of that electricity export to the rest of Pakistan was validated against the IGCEP 2022 results.

The same hourly output profile was simulated and aggregated on a divisional level for all potential VRE plants in Balochistan, thus enabling a realistic simulation of annual energy supply and demand of various VRE plants in aggregate. Each plant is simulated with its location-specific hourly profile. As each location has a slightly different production pattern due to different temperatures and irradiation the cumulative output of all VRA plants in each hour is less than the cumulative maximum output of all plants. This is called the "portfolio effect". As a result, the real effective output of a portfolio of VRE plants is smoother and more predictable than from single plants. This makes it easier to forecast and stabilize the grid.

10 Current practice is for the relevant DISCO to decide the daily demand profile based on the load shedding pattern.

Figure 2.3: Demand in Pakistan under IGCEP 2022 for 2028 and simulated VRE production in Balochistan



2.1.4 Grid analysis and methodology

For grid analysis the 2028 NTDC grid Power System Simulator for Engineers (PSS/E) model[11] was obtained and used to simulate and verify the maximum capacity of suggested locations for utility-scale plants as well as to conduct a load flow analysis and estimate the cross-border capacity for exporting electricity to the remainder of Pakistan. Based on the length of the relevant transmission lines, the surge impedance loading (SIL) limit is used to model the transmission lines under safe loading conditions. For short-length transmission lines, 80 percent of the thermal loading limit of the relevant transmission line is used to maintain safe operational limits.

2.1.5 Financial Assumptions

All VRE plants are simulated using the same cost assumptions, considering economies of scale for larger plants. The financial model assumes a targeted return on investment of 18 percent for the developer as per NEPRA's historic approved Return on Equity in Upfront Tariff for Solar Power Plants. In the base case the debt will be provided at 10.4 percent, covering 75 percent of the total investment cost. Of the total debt amount, 80 percent is provided at eight percent in US dollar terms, and the remaining 20 percent is provided at 20 percent in Pakistani Rupees (PKR). The resulting weighted average cost of capital (WACC) is 12.3 percent. The US$ modeling includes four percent annual inflation. The US$–PKR conversion rate has been assumed as 300 PKR/US$. Cost tables and financial assumptions are summarized in Annex D: Financial and Economic Model.

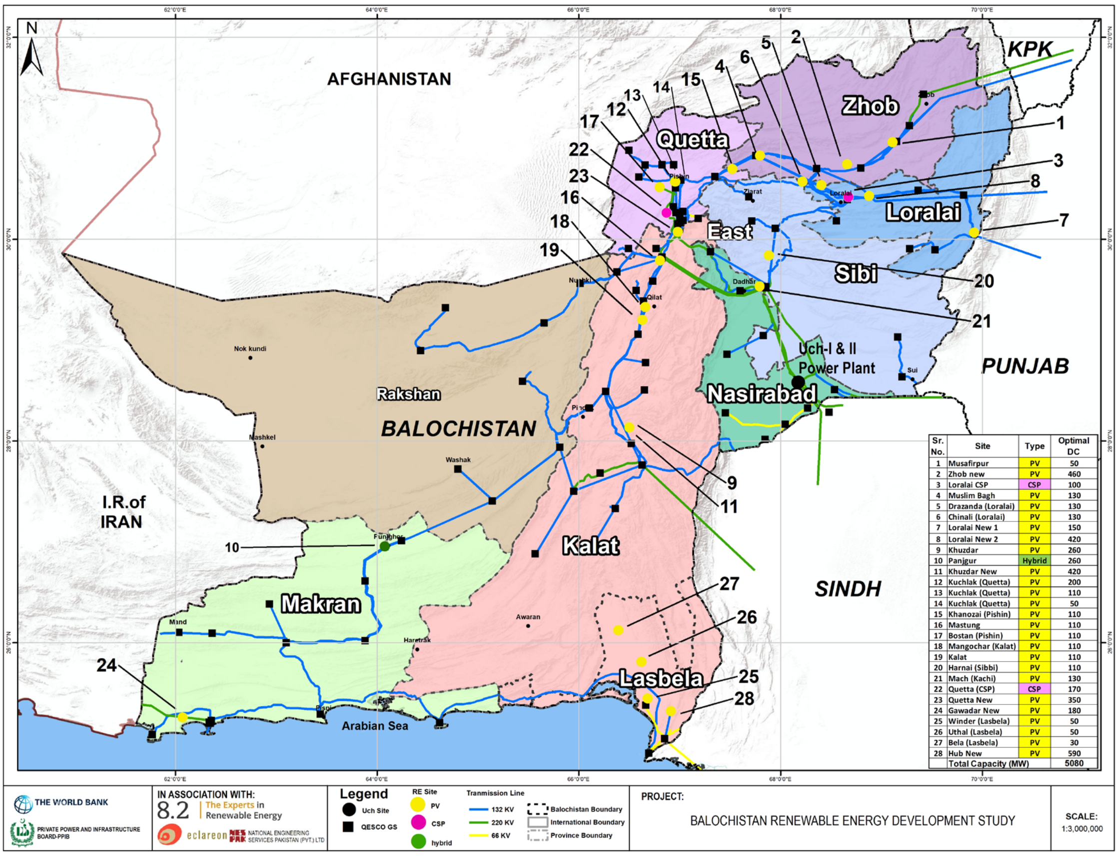
2.1.6 Evaluated Options

Until 2028 Utility-scale Plants on Existing Grid

The first proposed intervention is the development of low-cost PV and wind plants to supply energy to Balochistan and the rest of the country using the existing grid infrastructure. The result is that around 5 gigawatts (GW) of short-term opportunity in 25 plants (PV) have been identified and assessed to be feasible. Details are provided in Chapter 44.1 (Utility-Scale Plants).

11 In the 2028 NTDC model the latest IGCEP & TSEP has been incorporated by NTDC.

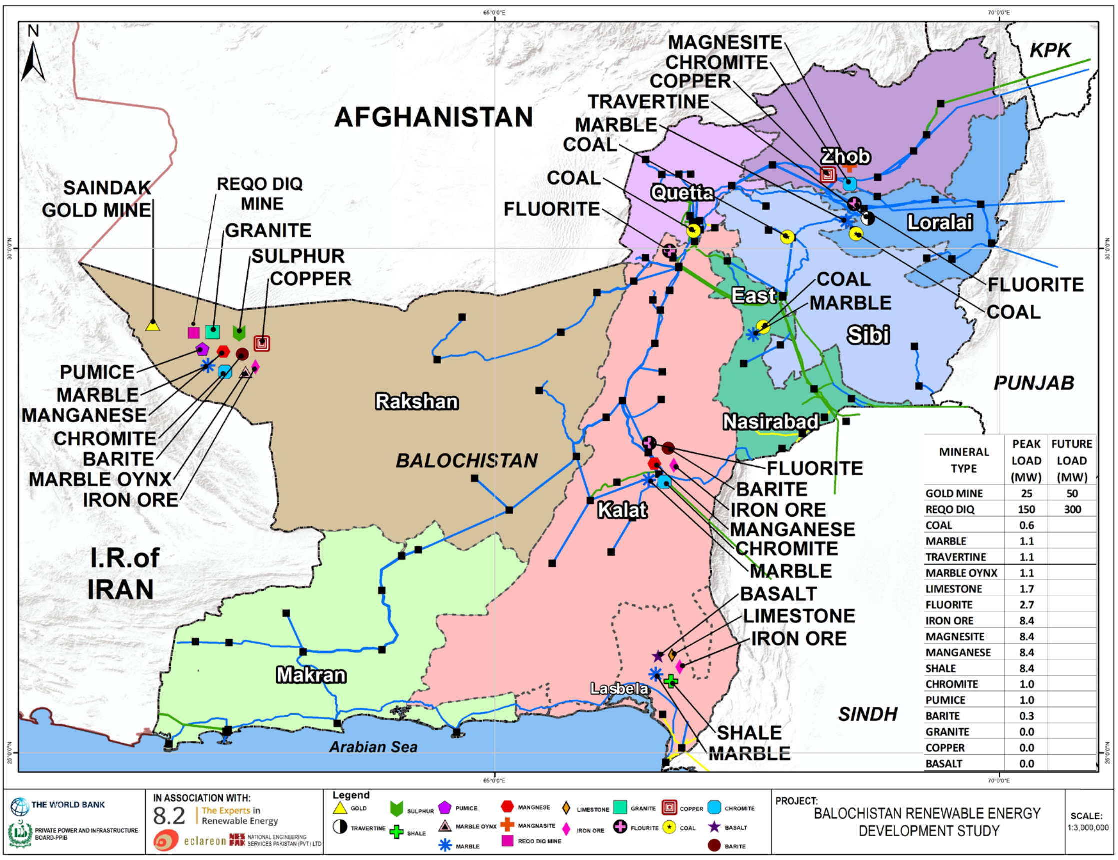
Figure 2.4: Utility-scale opportunities



Sr. No.	Site	Type	Optimal DC
1	Musafirpur	PV	50
2	Zhob new	PV	460
3	Loralai CSP	CSP	100
4	Muslim Bagh	PV	130
5	Drazanda (Loralai)	PV	130
6	Chinali (Loralai)	PV	130
7	Loralai New 1	PV	150
8	Loralai New 2	PV	420
9	Khuzdar	PV	260
10	Panjgur	Hybrid	260
11	Khuzdar New	PV	420
12	Kuchlak (Quetta)	PV	200
13	Kuchlak (Quetta)	PV	110
14	Kuchlak (Quetta)	PV	50
15	Khanozai (Pishin)	PV	110
16	Mastung	PV	110
17	Bostan (Pishin)	PV	110
18	Mangochar (Kalat)	PV	110
19	Kalat	PV	110
20	Harnai (Sibbi)	PV	110
21	Mach (Kachi)	PV	130
22	Quetta (CSP)	CSP	170
23	Quetta New	PV	350
24	Gawadar New	PV	180
25	Winder (Lasbela)	PV	50
26	Uthal (Lasbela)	PV	50
27	Bela (Lasbela)	PV	30
28	Hub New	PV	590
	Total Capacity (MW)		5080

The analysis also includes a flagship opportunity at Reko Diq mining site with 150MW energy needed for its first phase (until 2028). This in effect proposes a shift of the mining industry, the major industry in Balochistan, from fossil fuels to RE. Details are provided in Chapter 4.2 (Demand from Mining until 2028).

Figure 2.5: Mining locations



MINERAL TYPE	PEAK LOAD (MW)	FUTURE LOAD (MW)
GOLD MINE	25	50
REQO DIQ	150	300
COAL	0.6	
MARBLE	1.1	
TRAVERTINE	1.1	
MARBLE OYNX	1.1	
LIMESTONE	1.7	
FLUORITE	2.7	
IRON ORE	8.4	
MAGNESITE	8.4	
MANGANESE	8.4	
SHALE	8.4	
CHROMITE	1.0	
PUMICE	1.0	
BARITE	0.3	
GRANITE	0.0	
COPPER	0.0	
BASALT	0.0	

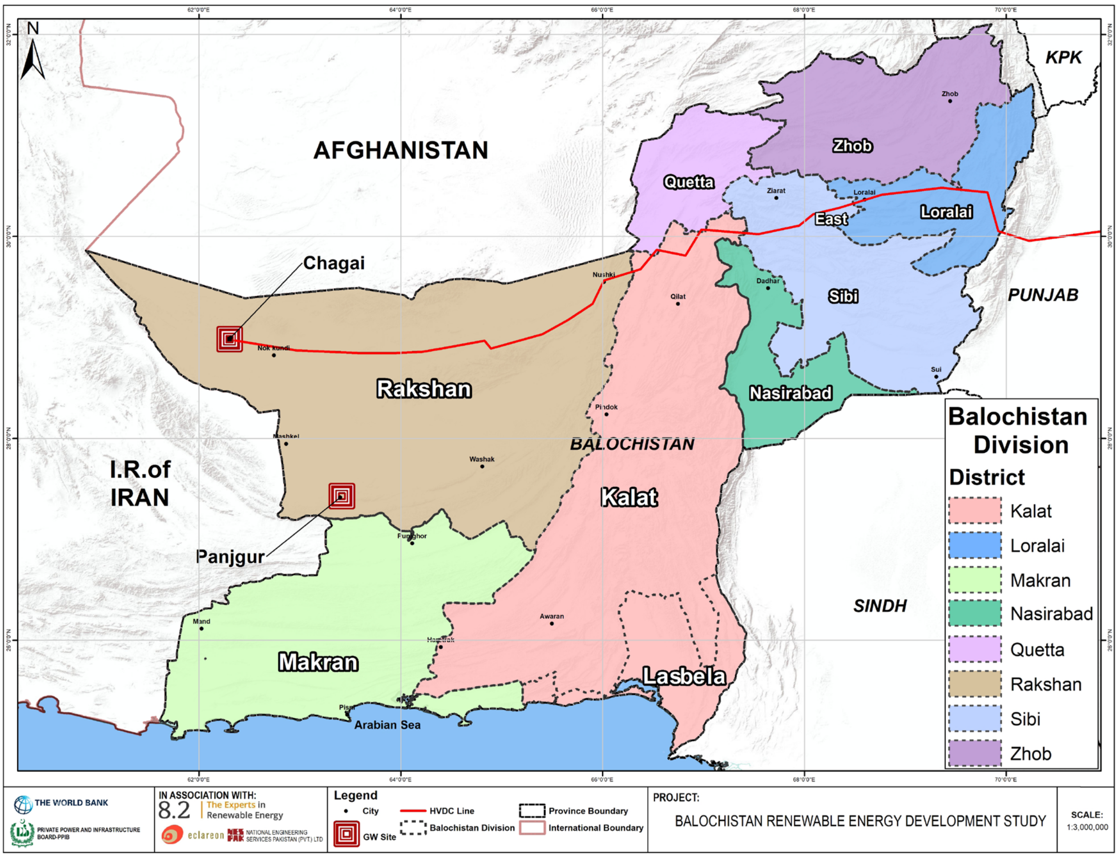
Until 2028 Distributed PV

Although it is not the primary focus of this study, a preliminary analysis was conducted for incorporating distributed solar systems/Photovoltaic (DPV) that could serve as a technical remedy for the significant losses experienced in 11 kilovolt (kV) lines. Implementation of such a solution would lead to a decrease in the local net electricity demand. That in turn would facilitate higher energy exports from utility-scale plants to the remainder of Pakistan. Nevertheless, the collective adoption of DPV might ultimately face restrictions due to limitations in the interprovincial line capacity and overall electricity demand. Details are provided in Chapter 4.3 (Impact of distributed PV).

Until 2033: Gigawatt Hybrid Parks

The analysis concludes that more reliable least-cost energy options are available in the long run (2033) where up to 9 GW of solar and wind could be developed in stages as a large hybrid park. New transmission lines are proposed as a long-term intervention. This would allow integration of one or more GW-scale VRE hybrid parks of wind and PV with a combined grid utilization of approximately 60 percent. Such parks are likely to have lower costs and risks than large hydropower projects, which have a grid utilization of some 55 percent. Details are provided in Chapter 5.1 (Gigawatt Hybrid Park).

Figure 2.6: Gigawatt opportunities



Surplus electricity generated from such GW-scale parks might be exported to Central Asia and Iran in the winters at a 20 percent profit margin. Financial details are provided in Chapter 5.2 (Electricity Export Options).

Depending on the amount of surplus energy produced by the parks, it could be transmitted through an additional line for production of green hydrogen around Gwadar. Ammonia can be used locally for fertilizer production to reduce dependence on Pakistan's depleting gas reserves. A feasibility study needs to be prepared to evaluate this option in detail. Further information is provided in Chapter 5.3 (Green Ammonia (Hydrogen)).

2.1.7 Economic and Social Considerations

The economic and social considerations of the proposed VRE interventions are discussed in detail in ANNEX B: Socioeconomic Impact.

The following considerations have been assessed:

- Impact on job creation;
- Impact of increased employment on GDP,
- Impact of new RE investments on GDP, and
- Reduction of greenhouse gas (GHG) emissions.

The impact on job creation has been assessed in the adapted World Bank (2022) methodology. The newly created jobs (direct and indirect) in onshore wind and solar PV (grid scale) in three project phases (development & preconstruction; construction; and operation & maintenance) have been estimated.

Greater employment opportunities (permanent) would have an income effect on GDP, resulting in growth in the economy. In order to measure the income effect on GDP, the multiplier estimated by Saikh (2015) has been employed. This approach measures the effect on both local and regional GDP, which is determined by the quantity of newly generated employment opportunities and subsequently estimates the average annual wage.

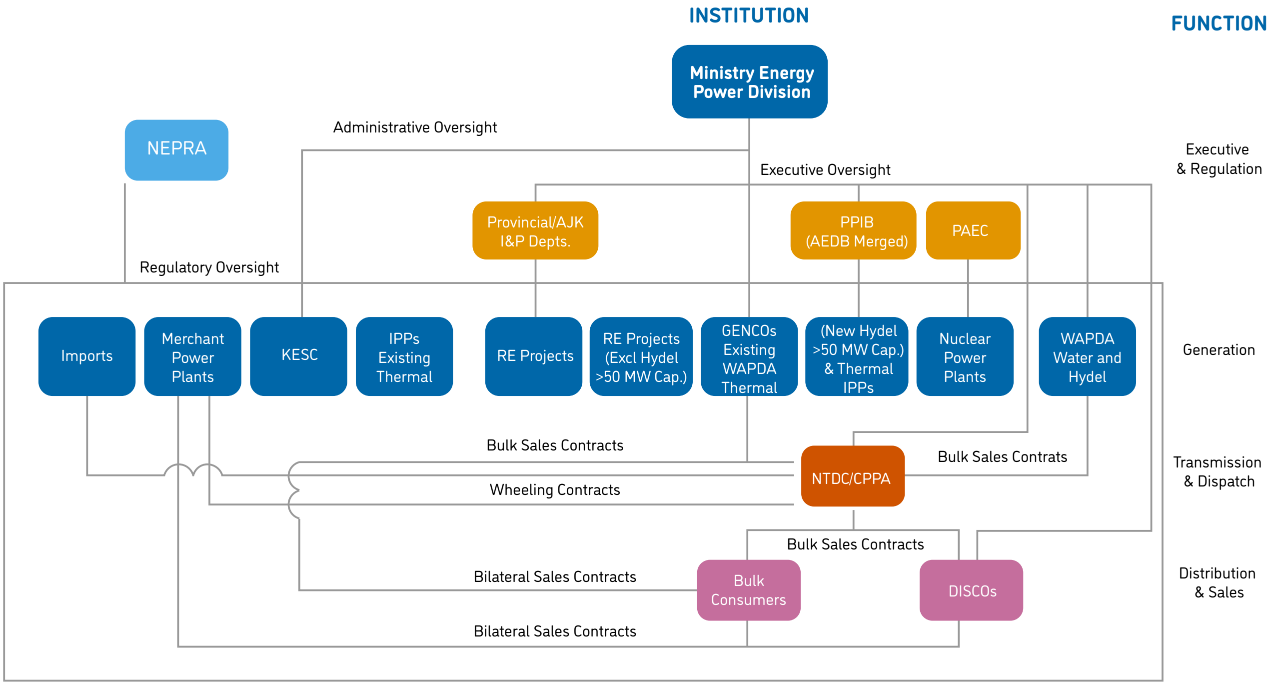
2.2 Status of Electricity Sector in Pakistan and Balochistan

The electricity sector of Pakistan is segmented—namely generation, plus transmission, plus distribution. All segments are centrally driven by government institutions even though electricity generation has some IPPs, and Karachi has a privatized DISCO. Legislation of more competition in the power sector exists in the form of a CTBCM market operator license for CPPA granted by NEPRA on May 31, 2022, though implementation is pending.

2.2.1 Power Sector Stakeholders

The main power sector institutions of Pakistan can be viewed in the figure below.

Figure 2.7: Organizational structure of Pakistan's power sector (basic)



Source: AEDB (AEDB, 2006) (Adopted with PPIB / AEDB merger in 2023)

National Electric Power Regulatory Authority

NEPRA is an independent regulatory body that oversees the electricity sector in Pakistan. It is responsible for regulating electricity generation, transmission, and distribution; setting tariffs; promoting competition; ensuring quality standards; and protecting the interests of consumers. NEPRA also resolves disputes and issues licenses to market participants in the power sector and is responsible for ensuring that the electricity sector is operated in a fair and transparent manner.

Federal Ministry of Energy – Power Division

The Ministry of Energy has two divisions, namely the Petroleum Division and Power Division. The Power Division is responsible for overseeing and implementing policies related to the power sector. The Power Division plays a crucial role in ensuring a reliable and sustainable power supply across Pakistan through its regulatory frameworks and collaborations with stakeholders.

The power division has a number of departments and agencies that work on various aspects of the energy sector, including:

- PPIB / AEDB;
- CPPA;
- NTDC; and
- Distribution Companies (DISCOs).

Private Power Infrastructure Board and Alternative Energy Development Board

Since May 2023, when AEDB—which was established to promote and develop RE in Pakistan—merged with PPIB, the PPIB has become the governmental agency responsible for promoting and developing RE in the country. The responsibilities continue to include formulating policy, implementing RE projects, and facilitating investment in sectors such as wind, solar, biomass, and hydropower, with the aim of diversifying Pakistan's energy mix and reducing dependency on fossil fuels.

Central Power Purchasing Agency

The CPPA is a public company wholly owned by the government of Pakistan: it is the centralized entity responsible for procuring electricity from power generation companies and distributing it to DISCOs. It ensures the equitable and transparent purchase of electricity from both public and private power producers and manages the settlement of payments to various stakeholders in the power sector. Since June 2015, the Central Power Purchasing Agency-Guarantee (CPPA-G) has assumed the business of the NTDC pertaining to market operations. The function and mandate of CPPA-G are regulated by NEPRA Market Operator Rules.

National Transmission and Dispatch Company

The NTDC is a publicly owned company responsible for operating and managing the national transmission system in Pakistan. It ensures the reliable transmission and dispatch of electricity from power generation sources to DISCOs, industrial consumers, and other load centers across the country.

Distribution Companies

DISCOs are the regional electricity distribution companies operating in different areas of Pakistan. Currently, there are ten DISCOs across the country, such as Lahore Electricity Supply Company (LESCO), Islamabad Electricity Supply Company (IESCO), QESCO, and others, responsible for the distribution of electricity to end consumers within their respective regions. They manage the billing, collection, and distribution infrastructure, ensuring reliable electricity supply to end consumers. In addition, Karachi Electric (KE), the Karachi-based DISCO, also possesses a distribution license to supply the electricity in its designated service area.

At a regional level, QESCO, a DISCO based in Quetta, covers the Province of Balochistan with the exception of the southeast, which is covered by KE.

Balochistan Energy Department

The BED is the authority responsible for the energy sector in the province. It formulates policies and plans and implements projects related to energy generation, transmission, and distribution within the Balochistan region, with the objective of meeting the energy needs of the province and promoting sustainable development.

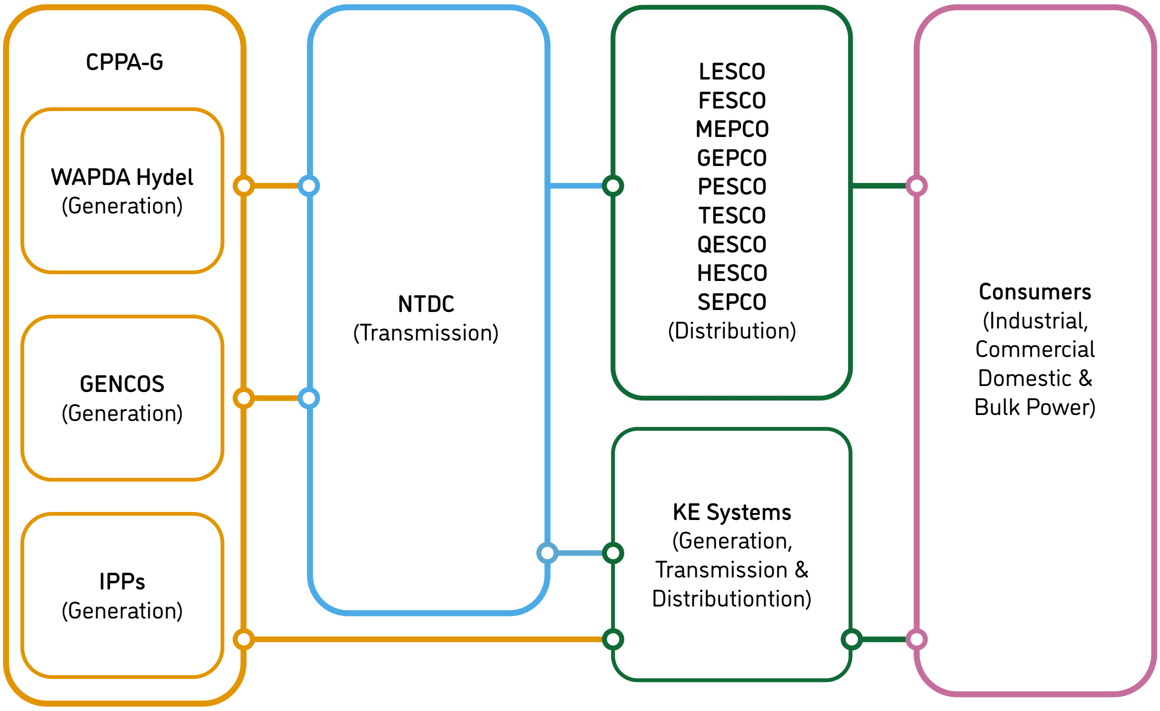
Balochistan Energy Company Limited

The BECL is a public limited company that was incorporated in 2012 to facilitate and foster all of the province's energy-related interests. Its main objective is to plan, promote, organize, and implement programs for the exploration and development of oil, gas, and renewable and alternate energy resources in Balochistan. Regarding RE projects, BECL is cooperating or in joint ventures with private developers whereby BECL mainly provides the publicly owned land in return for an equity stake. BECL plans to develop several solar PV projects in the near future.

2.2.2. Electricity Grid

Pakistan's electricity grid consists of generation, transmission, and distribution segments, as shown in the following diagram:

Figure 2.8: Electricity market segments of Pakistan



Generation

As per the NEPRA State of Industry Report 2022, Pakistan's installed electric power generation capacity on June 30, 2022, stood at 43,775 MW, which includes 40,813 MW in the CPPA-G system and 2,962 MW in the KE system. Similarly, Pakistan's available capacity on June 30, 2022, stood at 40,532 MW, which included 37,858 MW in the CPPA-G system and 2,674 MW in the KE system.

The generation systems are as follows:

1. CPPA-G system;
2. State-owned Generation Companies (GENCOs);
3. IPPs;
4. WAPDA Hydel; and
5. KE system.

Transmission

The NTDC is responsible for the single widespread 220kV and 500kV transmission system of Pakistan (except KE system). As the national grid company, its responsibility includes removing the constraints of the transmission system and integrating the TSEP with the IGCEP to implement an integrated expansion plan on a least-cost basis.

The NTDC is also responsible for the evacuation of power from the hydroelectric power plants (HPPs) (mainly in the north), the thermal units of the public sector (GENCOs) and private sector (IPPs) (mainly in the south) to the DISCOs through the primary (EHV) network. Its core functionalities are as follows:

I. Transmission network operator (TNO);

II. Operation and maintenance (O&M) of 500/220kV network, planning, design and construction of the new 500/220kV system and strengthening/upgrade of the existing system;

III. System operator;

IV. Arranging nondiscriminatory, nonpreferential economic dispatch, ensuring a safe, secure, and reliable supply;

V. Wire business:

- Transmission planning,
- Design and engineering,
- Project development and execution,
- O&M of transmission assets; and

VI. System operation and dispatch:

- Generation dispatch,
- Power system operation and control.

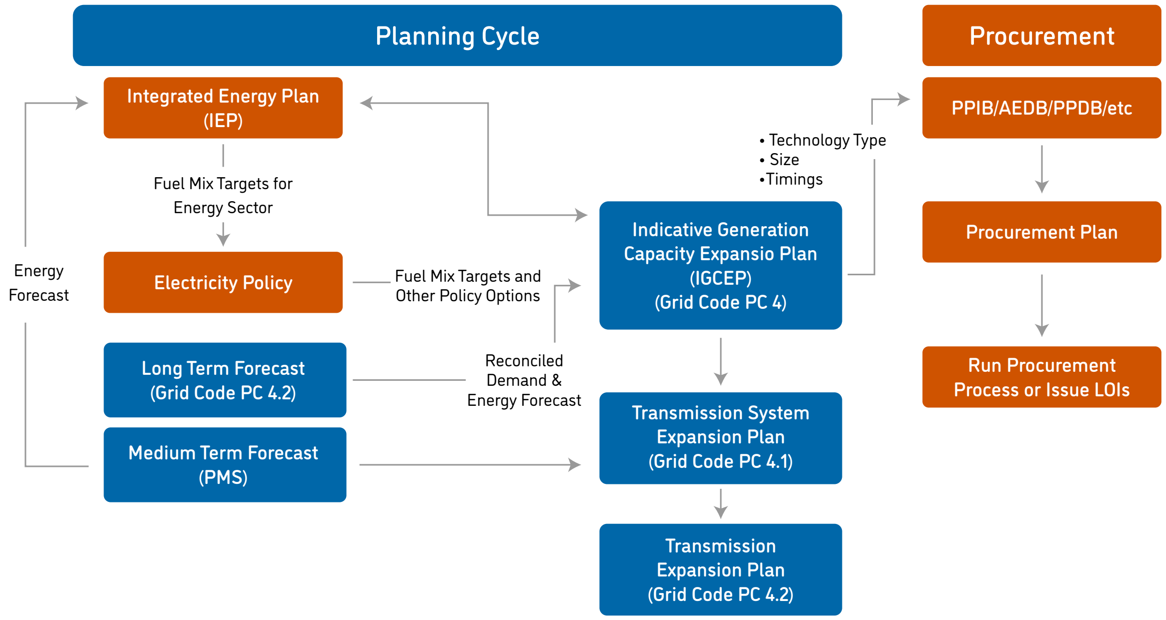
Distribution

After the unbundling of WAPDA in 1998, the distribution network (132kV, 11kV & 400V) was handed over to 10 DISCOs (including QESCO in Balochistan), except for a Karachi-based supply company which was privatized and named Karachi-Electric (KE) which now holds the license for generation, transmission, and distribution for the Karachi region. The entire electricity supply chain is dependent upon the performance of the DISCOs which are also the supplier of last resort and are liable to recover the billed amount and meet the NEPRA targeted transmission and distribution losses. During 2021–22, the allowed transmission and distribution losses for the DISCOs were 13.41 percent, whereas actual losses were 17.13 percent.

2.2.3. Power Planning Cycle

Every year, the NTDC performs its 10-year Indicative Generation Capacity Enhancement Plan (NEPRA, 2022). The IGCEP identifies potential VRE opportunities in blocks instead of specific sites, except for plants that have already been committed. Final solar and wind sites are selected by the PPIB under reverse bidding as shown in the planning and procurement cycle in the figure below.

Figure 2.9: Planning cycle leading to procurement



Source: IGCEP (NEPRA, 2022)

The other major consideration is the transmission system. The site has to be included in the TSEP and, if required, grid reinforcement/expansion should be reflected in the Transmission Investment Plan (TIP). For the procurement process, the PPIB prioritizes the Interconnection Ready Zones, areas already vetted for the integration of VRE. The site can be offered for reverse bidding based on land availability or substation/grid connection point.

Load forecasting is done at the DISCO level based on the Power Market Survey. The NTDC prepares the IGCEP and TSEP and models them using PSS/E software based on load forecasting data from DISCOs, generation data from the PPIB, CPPA-G, and so forth.

Recently a Competitive Trading Bilateral Contracts Market (CTBCM) has been established by NEPRA.[12] CTBCM allows for bilateral contracts of electricity supply using the grid infrastructure for a service fee. Therefore, CTBCM has introduced an additional Market Operator and System Operator. However, currently there is no electricity traded under the CTBCM regime and it remains unclear when electricity will be traded, or how much. As this study focuses on the least-cost supply for VRE electricity from Balochistan—which is independent of the purchaser of the electricity—and given that any involvement of CTBCM is unclear, CTBCM specifics have not been considered for this study.

2.2.4. Bidding Regime in Pakistan

A VRE competitive bidding study was conducted in 2022 by the World Bank, which found that competitive bidding could take 2–4 years from the start of bidding to a project achieving a commercial operation date (World Bank, 2022).

Competitive bidding is an effective way to procure VRE capacity at a competitive price and help ensure projects are developed in a timely and efficient manner—in contrast to unsolicited projects that may have a longer development cycle and may not synchronize with Pakistan's power planning. As for technology selection, the decision should be left to developers and the competitive bidding schemes. For this study, project selection by competitive bidding is assumed.

12 Please refer to the NEPRA website, CTBCM page.

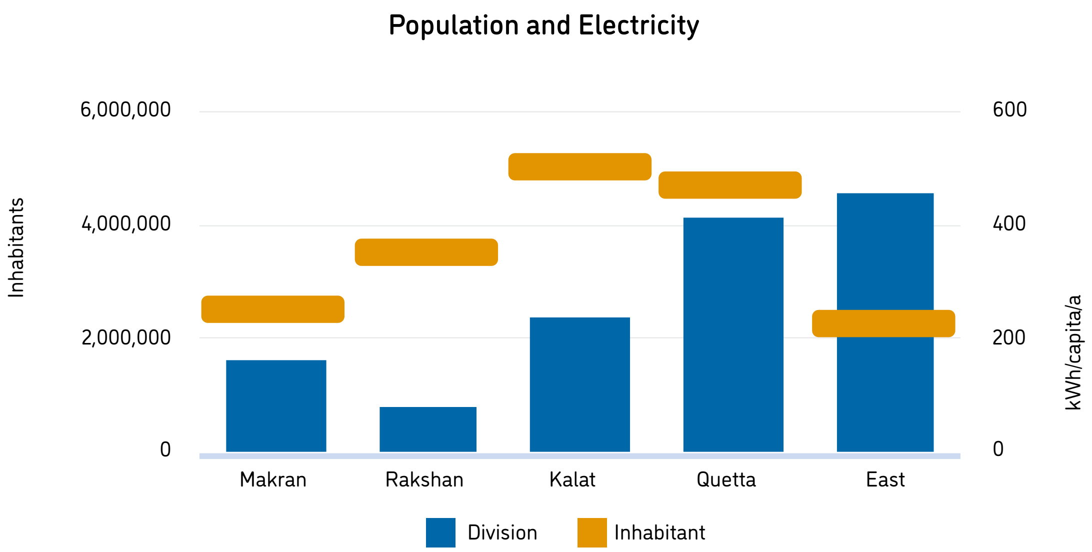
VRE electricity used through CTBCM regulations would be another way of financing. In this case the electricity will not be purchased by CPPA-G but from a third party.

2.2.5. Demand and Supply in Balochistan

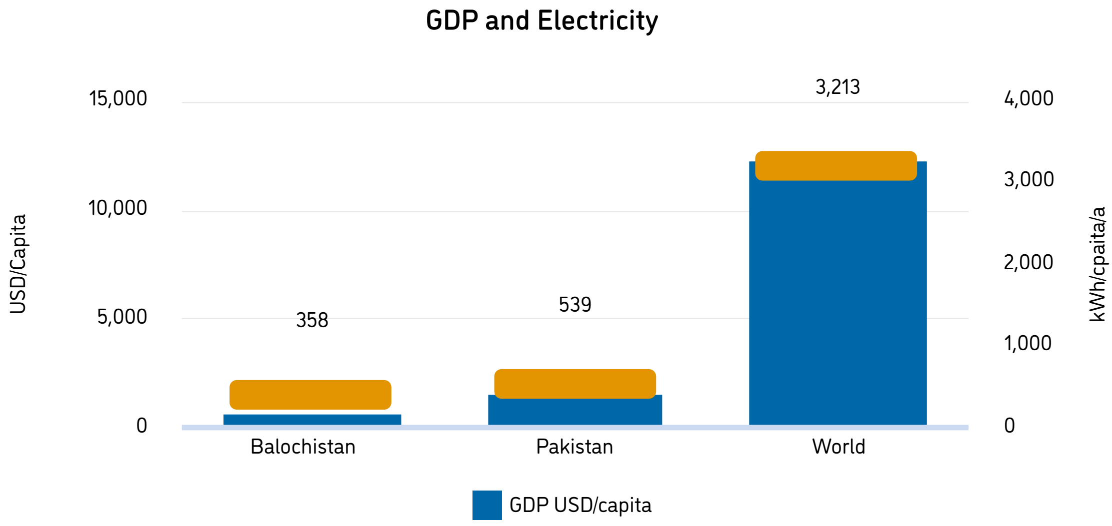
Electricity consumption per capita and GDP per capita in Balochistan are with 615 USD/Capita in 2021 according to (the lowest in Pakistan (1504 USD/Capita) and very low as compared to the global average. Balochistan comprises around 43.6 percent of the area of Pakistan but with slightly in excess of 20 million inhabitants only houses eight percent of the country's population.[13] Approximately 13.4 percent of Balochistan's population live in the metropolitan area of its capital, Quetta. Roughly 57 percent of the population has access to grid electricity across the province[14] and QESCO administers around 90 percent of the grid electricity supply within the province (NTDC, 2019). In the southeast district of Lasbela, KE supplies the remainder from Karachi.[15]

The western divisions of Balochistan are even more sparsely populated and less developed than the other divisions. These areas receive minimal rainfall, and rivers are limited to the eastern part of the province. As a result, the primary factor driving the demand for electricity in this area is irrigation for agricultural purposes. In the eastern division, surface water is available through the Indus basin and, as a result, per capita electricity consumption for agriculture is less than in other divisions.

Figure 2.10: Balochistan GDP and Electricity Consumption



13 Reported population of Pakistan, according to the interim data from the "7th Population and Housing Census-2023"
14 Pakistan Energy Survey Report, World Bank, 2022.
15 Statistical data used for this study considers actual QESCO network data, and it is assumed that KE network data would be similar.



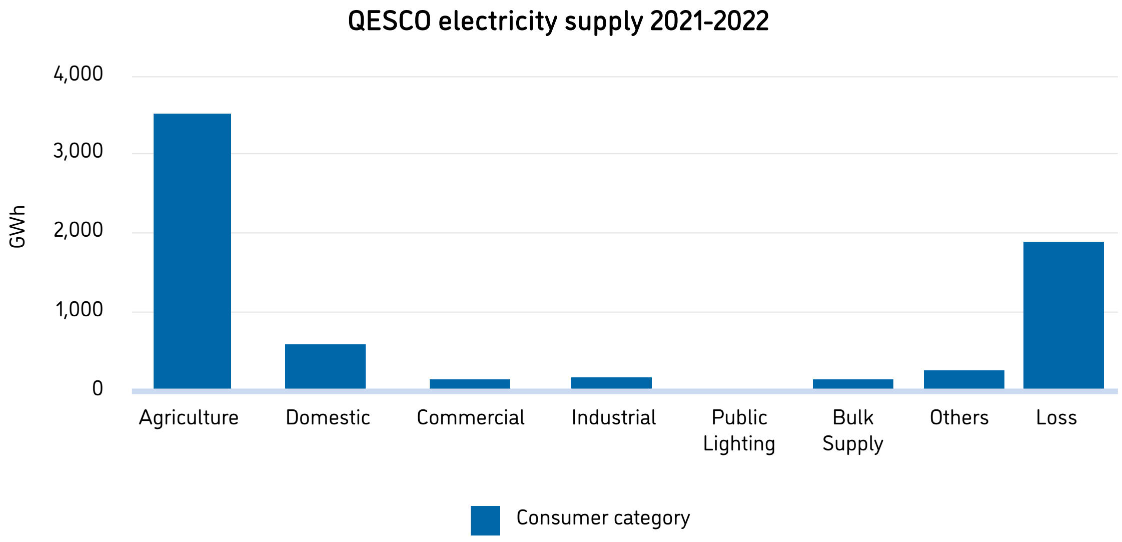
Source: (QESCO, 2021); World Bank 2021 (Pakistan Data)

Local farmers account for roughly 75 percent of the total energy demand for irrigation purposes. Electricity for farmers is distributed through 748 11 kV feeders. Since the population is distributed over a vast area, the average distance per feeder is 56.88 km, leading to significant losses during peak hours. In order to manage the load, QESCO implements extended periods of load shedding, sometimes more than 16 hours a day, which results in an unusually high load when the grid is available. This approach—severe load shedding—has a negative impact, as it condenses the load into shorter time frames, leading to increased losses as depicted in figure 2.11. Distributed PV is increasingly being adopted by farmers to reduce their dependence on the already insufficient grid electricity supply.

The main financial crunch faced by QESCO is due to the reluctant attitude (nonpayment culture) of agricultural consumers despite an agricultural subsidy agreement that allows certain farmers to run a 30 KW tube well for some six hours a day. Under the agreement, only 4.33 percent of agricultural customers account for more than 72 percent of total electricity demand in QESCO's area of operation; and approximately 88 percent of QESCO's revenue relies on recovery from agricultural customers. In reality, farmers have installed more capacity than was provided in the agreement and are not paying for any additional electricity consumed. Meanwhile, the farmers claim not to use more electricity than granted by the subsidy but need to install more capacity simply because QESCO reduces availability through load shedding. As most of the connections are not metered, QESCO cannot attribute the exact electricity consumption to individual farmers or substantiate obligations (their bill). In 2022/23 the losses of QESCO in the farming segment, including subsidy and line losses, amounted to US$340 million.

For electricity supply, there are two gas plants (Uch I and Uch II) with approximately 930 MW capacity (NEPRA, 2022) at the eastern border of Balochistan. These are dependent on the Sui Gas Field, located about 650 km from Karachi in Dera Bugti, Balochistan. Gas production from the field is expected to peak in 2025 and decline sharply thereafter. The electricity is mainly exported to other provinces of Pakistan. In 2021–2022 the plants provided more than 7,100 gigawatt-hours (GWh) (NTDC, 2023), mostly exported to Punjab. There is a plan for an additional 300 MW imported coal-based plant close to Gwadar as part of the China–Pakistan Economic Corridor (CPEC) agreements under the Chinese Belt and Road Initiative. Here the government of Pakistan has itself committed to building a coal power plant with Chinese financing. However, the development of this load center is not progressing as fast as anticipated and, therefore, the implementation of the 300 MW coal-plant intervention may take longer than initially expected.

Figure 2.11: QESCO Electricity supply



Huge potential PV and wind sources have been identified in various locations and have the lowest cost across Pakistan. This is attributable to high solar irradiation (about 20 percent higher as compared to other parts of Pakistan) and corridors with a high wind capacity factor (50 percent in certain areas) (Global Wind Atlas). The land in the province is also mostly arid to semi-arid and is not costly. Despite the aforementioned benefits, no utility-scale PV and wind plant has been developed in the province. As mentioned earlier, ***with the sector being dominated by agricultural use for water pumping, agricultural customers are subsidized, but tariff recovery is at a historical low. Long distribution lines and intensive load shedding cause high line losses as well. These factors contribute significantly to Pakistan's chronic deficit of electricity supply which, in turn, requires a bail-out by the government every few years, commonly referred to as the "circular debt problem" (ADB, 2021).***

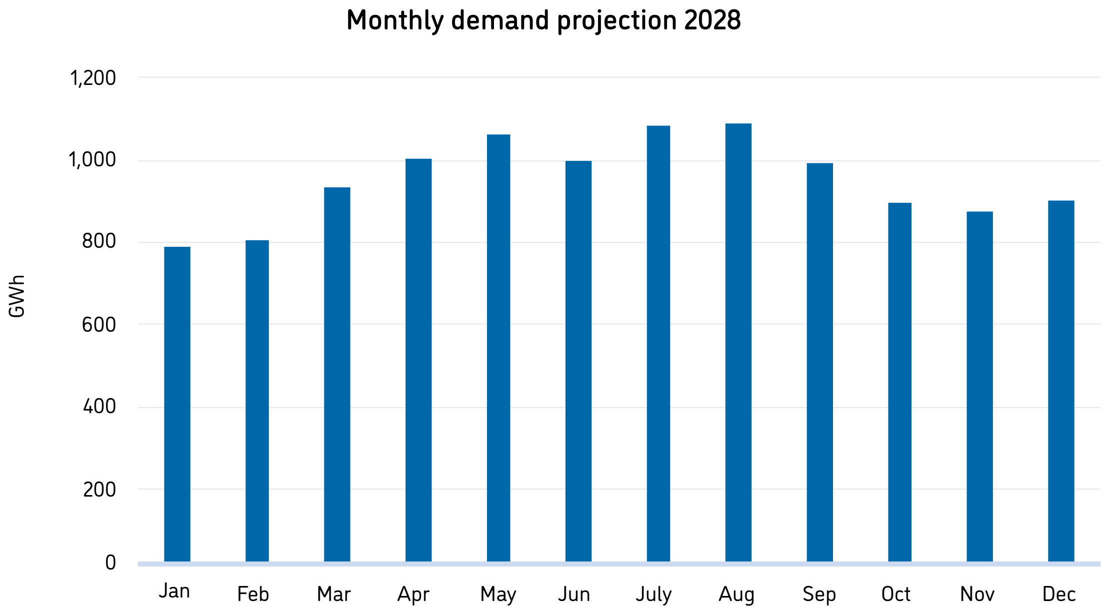
Figure 2.12: QESCO Profitability by Customer Group

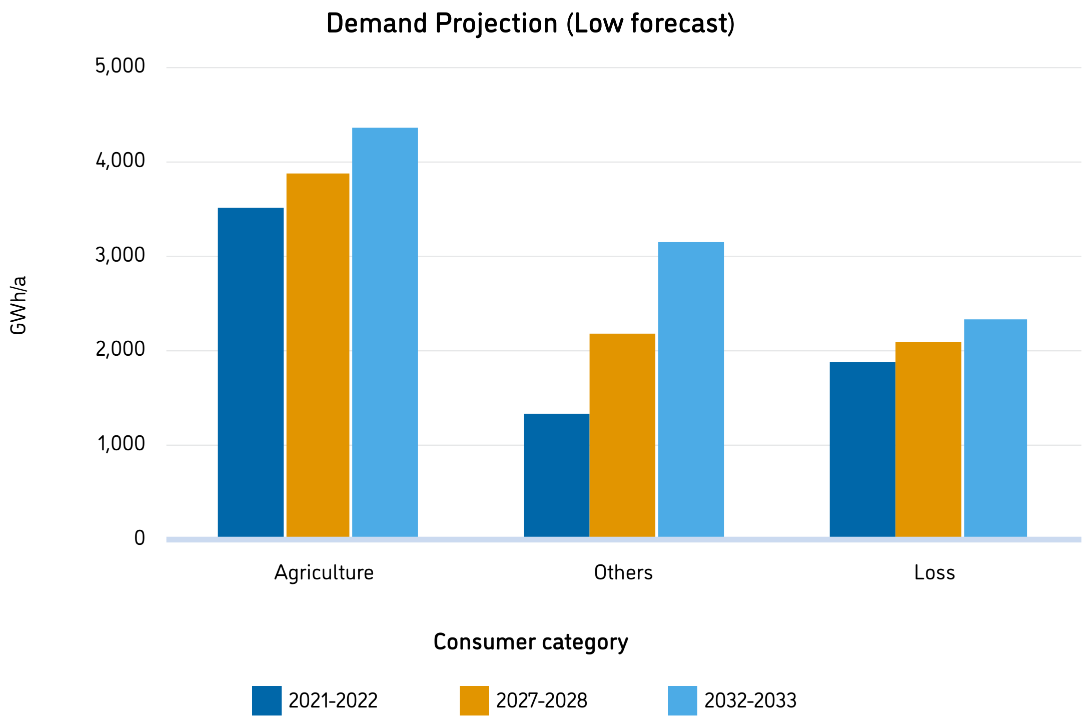
Source: (QESCO, 2021)

While the technical losses could be reduced through grid upgrades and DPV, a political solution is sorely needed to address the culture of nonpayment and resulting financial losses.

The demand forecast peaks generally in summer months with user segments all growing very similarly. The QESCO low-demand scenario has been used as a base case for this study to take a conservative view. This is backed by historic underperformance of expected growth in electricity consumption in Balochistan. In addition, a conservative local demand forecast will put more stress on the evacuation capacity as more electricity need to be exported. This makes the results of this study more robust.

Figure 2.13: Balochistan demand split and growth expectation, low forecast





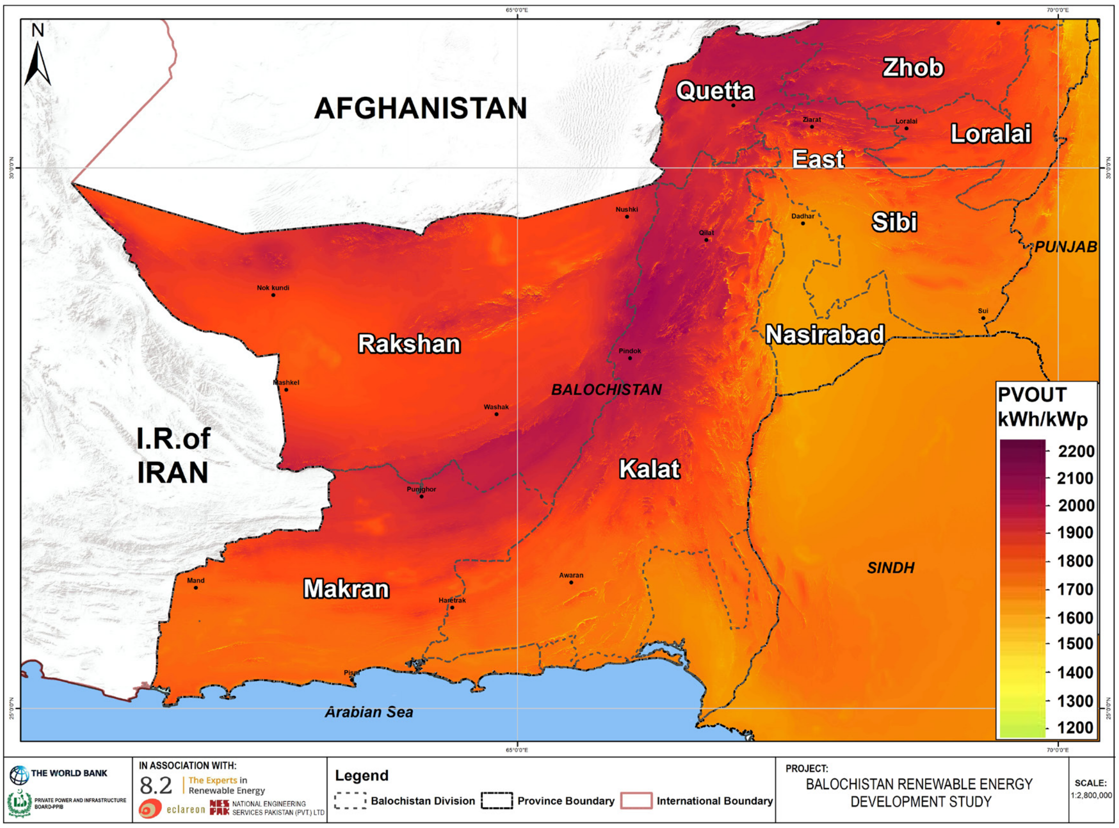
Source: (QESCO, 2021)

2.3 VRE Resources and Technology in Balochistan

2.3.1. Solar Photovoltaic Resource and Technology

Solar PV is the fastest growing, most universal form of RE technology today—and one of the cheapest. Its viability and profitability depend mostly on the solar irradiation in a given area. Ideal project sites should enjoy a minimum global horizontal irradiance (GHI) of 1,200 kilowatt-hours per square meter (kWh/m^2) per year. Balochistan offers an impressive range of 2,000 to 2,500 kWh/m2, making it one of the most abundant regions globally in terms of available resources (see figure below). When sized professionally, PV in Balochistan can achieve line utilization factors up to 40 percent, and its supply profile correlates positively with the demand profile.

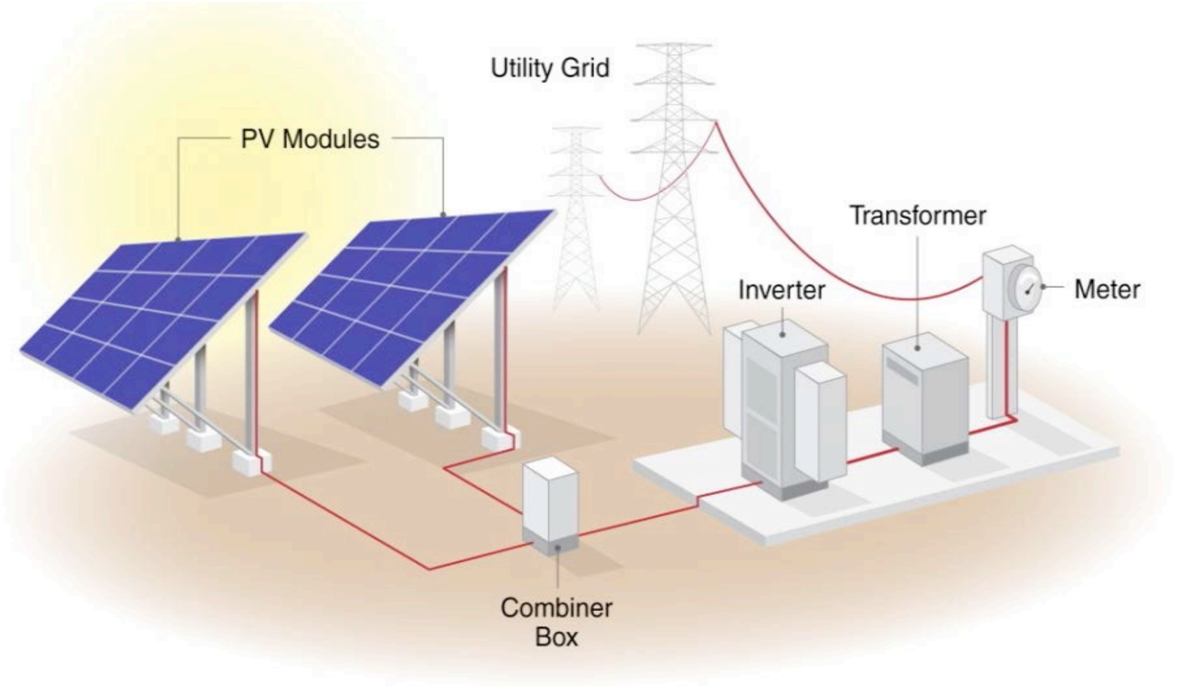
Figure 2.14: Energy output of solar PV plants in regions of Pakistan



Source: Global Solar Atlas

Solar PV is a modular technology, meaning that it is equally suited to small units (for example, rooftop solar) and large-scale plants. By capitalizing on economies of scale and implementing diligent maintenance practices, large-scale plants can attain optimal performance levels. Two distinct technical setups are possible: fixed structures, which are the most common and straightforward, with modules typically positioned facing south in the northern hemisphere; and one-axis tracking, where modules track the sun's movement from east to west throughout the day. Tracking has become cheaper and more standardized over the years and offers a higher yield per module as well as higher outputs during morning and evening, which makes the power more valuable from a grid perspective. One-axis tracking was therefore assumed in the analysis of this report.

Figure 2.15: Conceptual PV electricity generation system



Source: National Renewable Energy Laboratory, Facility-Scale Solar Photovoltaic Guidebook, 2016

The important parameters for PV site selection include the following:

Irradiance: Solar irradiance is higher in Balochistan than elsewhere in Pakistan; within Balochistan, it is higher toward the north, near Quetta, and in the center, in the Kalat region.

Temperature: At higher temperatures, the energy production of PV modules decreases. Heat losses in very hot areas can be as high as 4–5 percent. The relatively hot climate in Balochistan, however, does not make PV power less viable there.

Grid availability: For large solar parks of between 50–200 megawatts peak (MWp), a 132 kV grid is usually sufficient. Ideally the site should be 15–20 km from the grid substation or the line itself (for loop-in loop-out configuration). Sufficient capacity should be available in the grid to absorb the power produced by the solar plant.

Terrain: Although solar panels can theoretically be installed on any terrain, ideally the slope should not be more than 5 degrees.

Soiling losses and water availability: Soiling losses depend on the amount of dust in the area. Hot desert areas usually have higher soiling losses of 0.5 percent to 1 percent compared to nonarid regions. Water availability is required for cleaning the solar modules, but water usage is not as intensive as CSP technology.

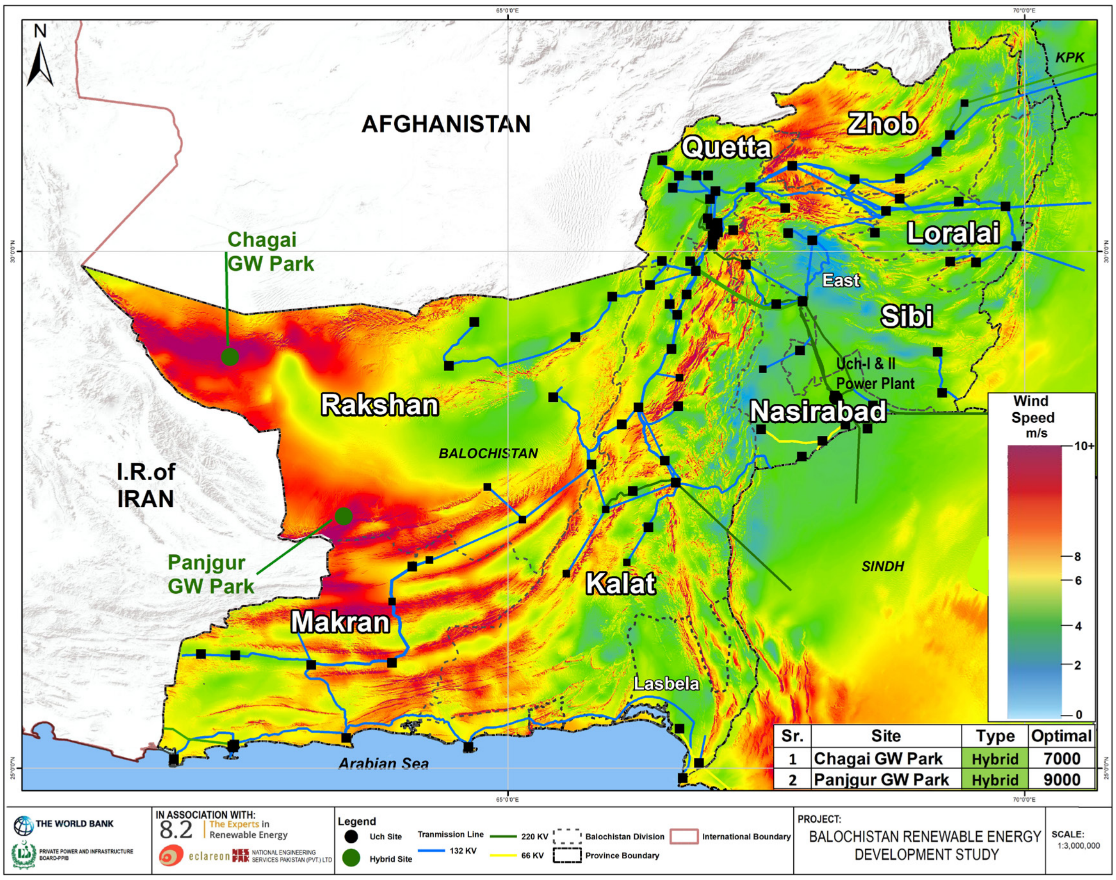
Table 2.1: Advantages and challenges for PV plants

Advantages	Challenges
• Excellent resource for PV in almost all of Balochistan (higher north of Quetta and in Kalat). • Very quick to construct (few months). • Least-cost technology for electricity. • No GHG emissions. • Good supply correlation with electricity demand.	• Only daytime power. • Fluctuation with weather. • Relatively low capacity factor (around 20–25 percent) depending on location and technology.

2.3.2 Wind Resources and Technology

Wind power is the VRE resource that contributes most to the global mix of VRE installed capacity. At the same time, it is one of the cheapest forms of energy. However, this affordability is only applicable to sites with consistent wind resources, which are more geographically restricted and localized compared to solar power. Balochistan has the best spots for wind power within Pakistan—located in the remote areas of Chagai and Panjgur in the west, with average wind speeds of up to 10 m/s at a height of 100m (figure 2.16). These areas' vast available space further enhances their potential for generating green energy, especially wind at low costs.

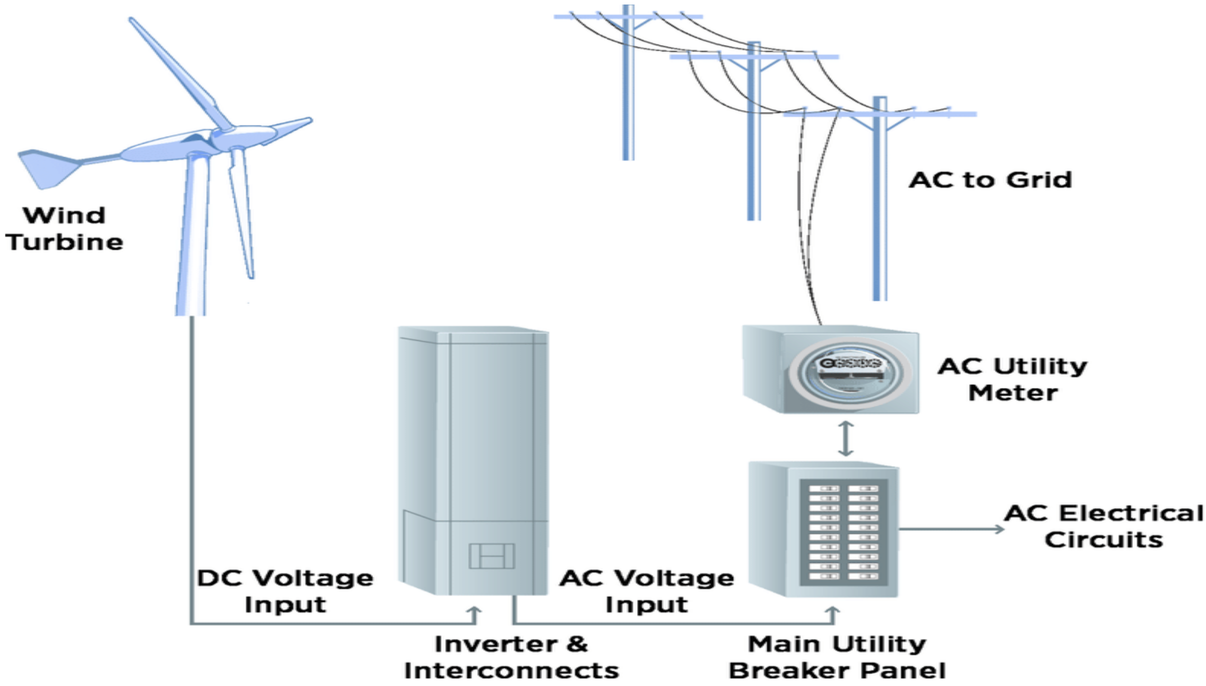
Figure 2.16: Average wind speed in regions of Pakistan



Source: Global Wind Atlas

Wind turbines catch the wind's energy with propeller-like blades; the most common design is a tall tower with three large blades on a horizontal axis. The trend is toward higher and larger wind turbines to achieve economies of scale. Wind power plants involve more mechanical and civil engineering than solar power plants, resulting in longer lead and construction times.

Figure 2.17: Schematic diagram of a grid-tied wind energy system



Source: USA National Renewable Energy Laboratory

Internationally, an important differentiation of available wind technologies is between onshore and offshore wind. In an onshore system, the wind turbines are typically mounted on towers that are 60 to 120 m high. In an offshore system, the wind turbines are installed using floating structures, usually in shallow coastal waters (sometimes in deeper waters). For Balochistan, offshore wind can be disregarded because all the important wind corridors are on land.

Table 2.2: Advantages and challenges of wind energy

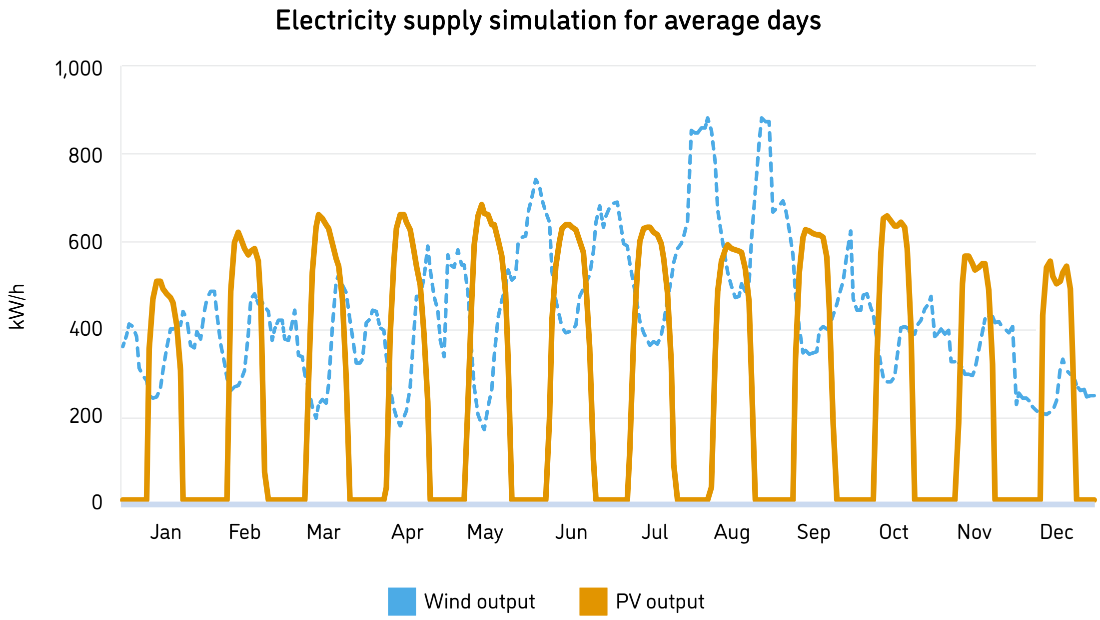
Advantages	Challenges
• Excellent resource for wind in western Balochistan (Chagai, Panjgur) • High capacity factors of up to 45 percent • Cheap source of power • Possible for hybridization with PV	• Longer lead and construction time than PV • Fluctuation with weather • Limited to certain locations

2.3.3 Hybrid Technologies

An interesting option particularly suitable for Balochistan is the co-location of PV and wind power systems on the same site. This approach offers several advantages: both technologies produce cost-effective and environmentally friendly electricity, and since wind and solar resources typically have noncorrelated time patterns, their outputs can be effectively combined. As a result, this integration enables high combined load factors with minimal energy curtailment, meaning that the grid infrastructure used for power evacuation can be utilized better, thus decreasing grid costs as well as the requirement for backup power.

The following graph (figure 2.18) shows the seasonal and diurnal PV and wind resources in the region of Chagai for 1 MW installed capacity each. The PV output profile is slightly better in this region compared to other provinces. A similar wind resource is only available at the red wind locations shown in the above map (Average wind speed in regions of Pakistan).

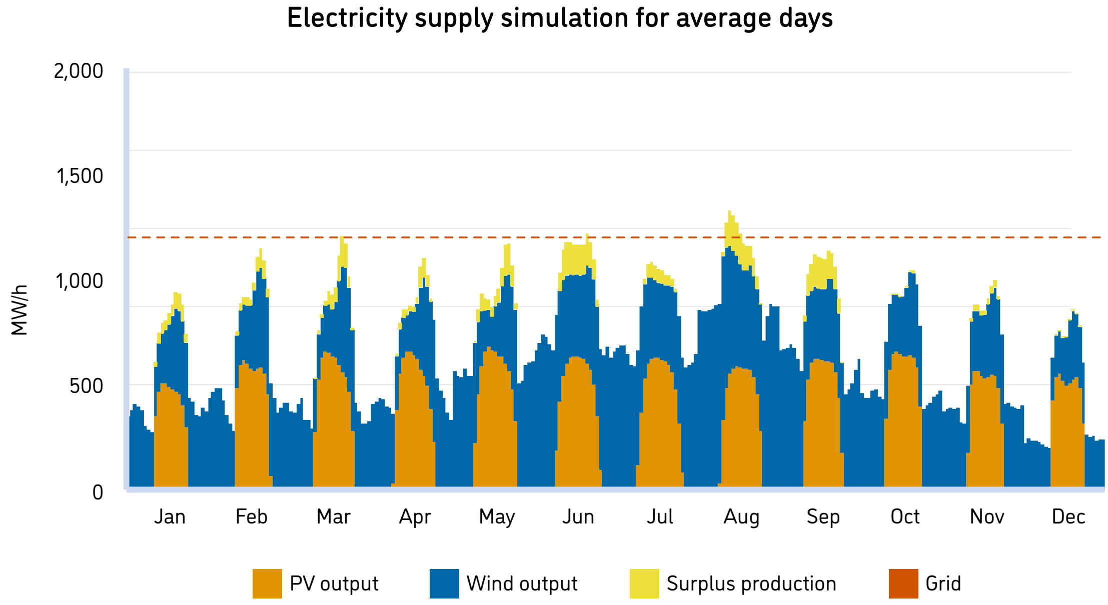
Figure 2.18: Seasonal and diurnal PV and wind resource



The complementary nature of both resources allows for an excellent PV-wind hybrid output with a grid (connection) utilization greater than 60 percent. Figure 2.19 shows the combined output of one MW each. If connected with an evacuation capacity of 1.2 MW to the grid hybrid grid, utilization would be at 57 percent, even though the combined installed capacity factor would only be at 34 percent. As grid utilization is an indicator of resource reliability and grid evacuation cost this factor will be used for further analysis in this study.[16]

16 The notional installed capacity factor assumes unlimited grid capacity, which is usually not the case.

Figure 2.19: Seasonal and diurnal hybrid resource

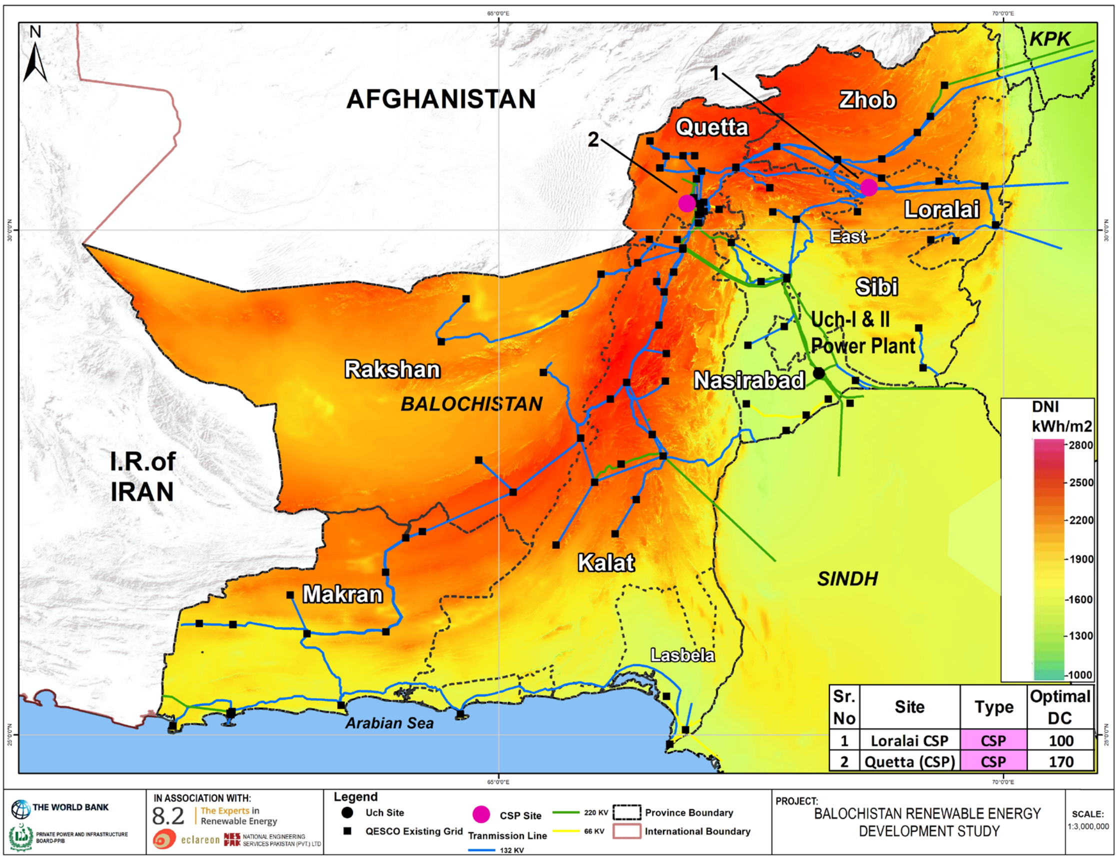


2.3.4 Concentrated Solar Power Technology

Unlike the more commonly known solar PV power, which fluctuates with changing solar irradiation, concentrated solar power (CSP) comes with cost-effective thermal storage, allowing higher predictability for planning purposes and a constant dispatch of electricity, but at a higher generation cost than PV. This generation cost of CSP depends largely on the available direct solar irradiation (known as direct normal irradiance or DNI). As mentioned earlier, solar irradiation in Balochistan as a whole is quite high (that is, GHI for PV: around 2,200 kWh/m^2 p.a.)[17] and DNI as the relevant resource for CSP technology is excellent with values of up to 2,500 kWh/m^2 per year (see Figure 2.20 below). CSP projects have been implemented at DNI levels of 2,000 kWh/m^2 (such as in Dubai), so 2,500 can be considered an excellent irradiation level.

17 Global Solar Atlas

Figure 2.20: DNI for CSP plants in regions of Pakistan



Source: Global Solar Atlas

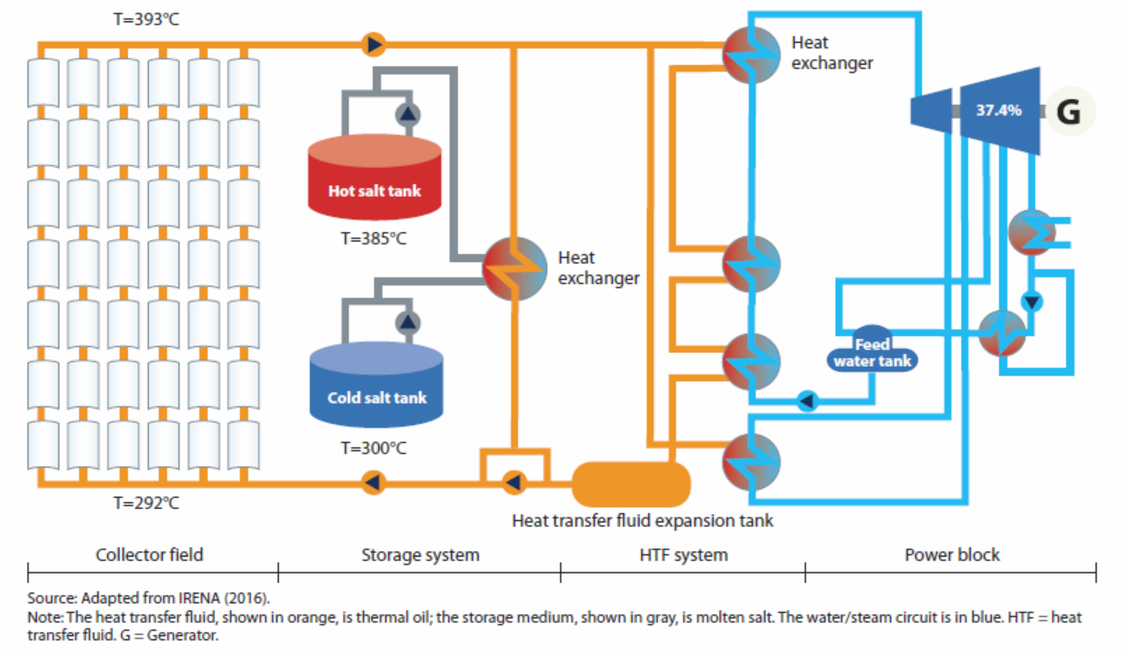
The viability of CSP as a power generation technology should not be seen in competition with PV but rather as an additional source of RE power with specific benefits such as constant power output, baseload capability, predictability, and the stabilizing effect on the local grid.

The two main designs used in today's commercial CSP plants worldwide are parabolic trough and centralized towers. Both have been successfully deployed worldwide, with centralized towers recently becoming more popular due to their better storage characteristics.

Parabolic Trough

The parabolic trough design was the first CSP setup that was built in commercial power plants and therefore, of all CSP designs, it has the longest track record and the highest amount of accumulated operational experience to date. Solar thermal power is collected along long pipes by means of a heat transfer fluid and converted into electricity in a steam turbine. Throughout the day, the mirrors in CSP systems follow the movement of the sun, directing its beams onto the receiver line by means of one-axis tracking. Storage is a crucial component in the majority of CSP plants under construction, as it enables a consistent power output. This stability in power generation serves as the primary advantage of CSP over PV or wind technologies. Storage is implemented as thermal storage with a system of a hot and cold salt tank, both containing liquid salt at a temperature of about 400 and 300°C, respectively. Power is generated in the power block, which contains the steam turbine and all required auxiliaries, similar to other thermal power technologies although optimized for the CSP plant's lower temperature levels. As larger turbines and power blocks are more efficient and have a lower cost, there are higher economies of scale for CSP compared to PV or wind power parks.

Figure 2.21: Schematic view of a parabolic trough CSP plant.

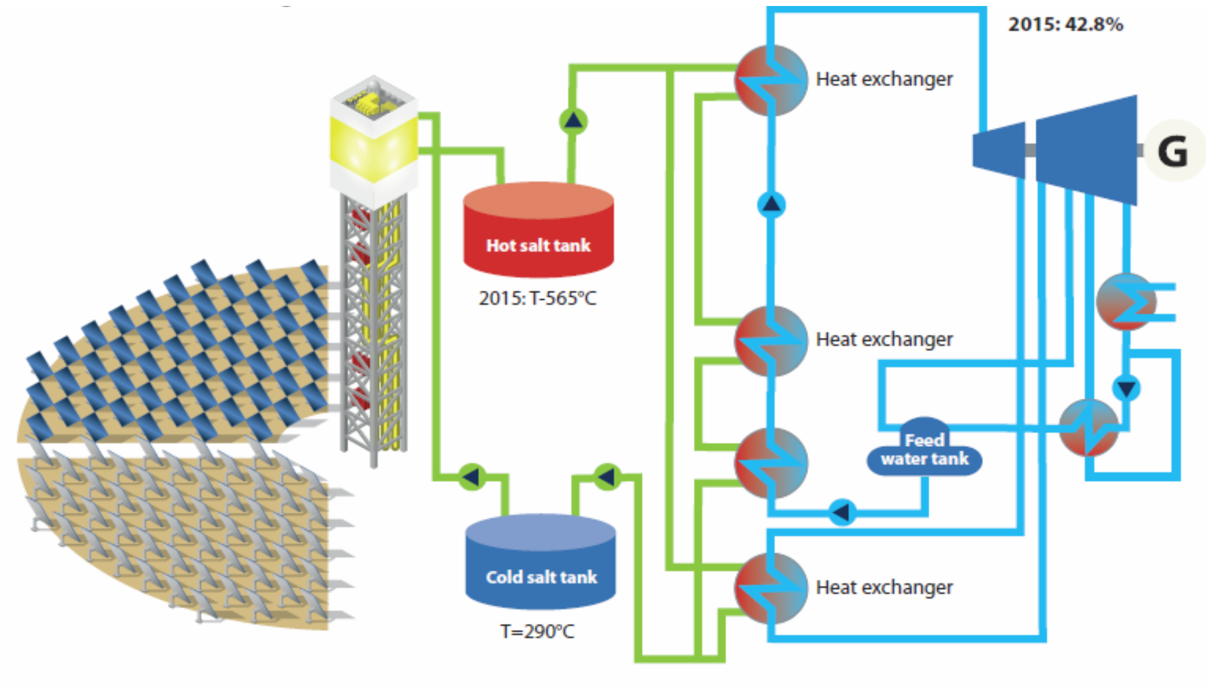


Source: (World Bank, IRENA, CIF, 2021).

Central Tower

In the central tower design, slightly curved mirrors (called "heliostats") are placed on individual support structures on the ground around a central tower. In the two-axis tracking system, all mirrors are continuously adjusting their positions to follow the sun's movement. This precise tracking enables the projection of concentrated solar beams onto a central receiver located at the top of the tower, where heat is collected. In many designs, molten 'salt' is utilized as a direct medium to capture and store heat. This approach eliminates the need for additional temperature exchange between the heat transfer fluid and the storage medium.

Figure 2.22: Schematic view of a tower CSP system.



Source: (World Bank, IRENA, CIF, 2021)

Conclusion

For Balochistan, both the parabolic trough and central tower designs could be utilized; the following table shows pros and cons of both options. Most of the numbers and features (like costs, area requirements) which are estimated in the case study section on CSP (Chapter 4.1.3) are applicable for both designs.

Table 2.33: Comparison of trough and tower technologies

Parabolic trough	Central tower
• Technology with the longest track record so far, sometimes preferred by investors. • Components and design more standardized than for tower. • Modular design of solar field; less risk of complete destruction (for example, through solidifying of salt for tower plants).	• Higher temperatures in receiver and storage, leading to higher efficiencies. • Energy production across the year is more homogeneous. • Can be built on land with a slight inclination.
Common features of all CSP technologies	
• PRO: Storability, constant dispatch, high capacity factor, grid services. • CON: Higher costs than PV and wind, limited to high-DNI locations, greater water requirements than other technologies.	

3. Electricity Demand and Grid Analysis

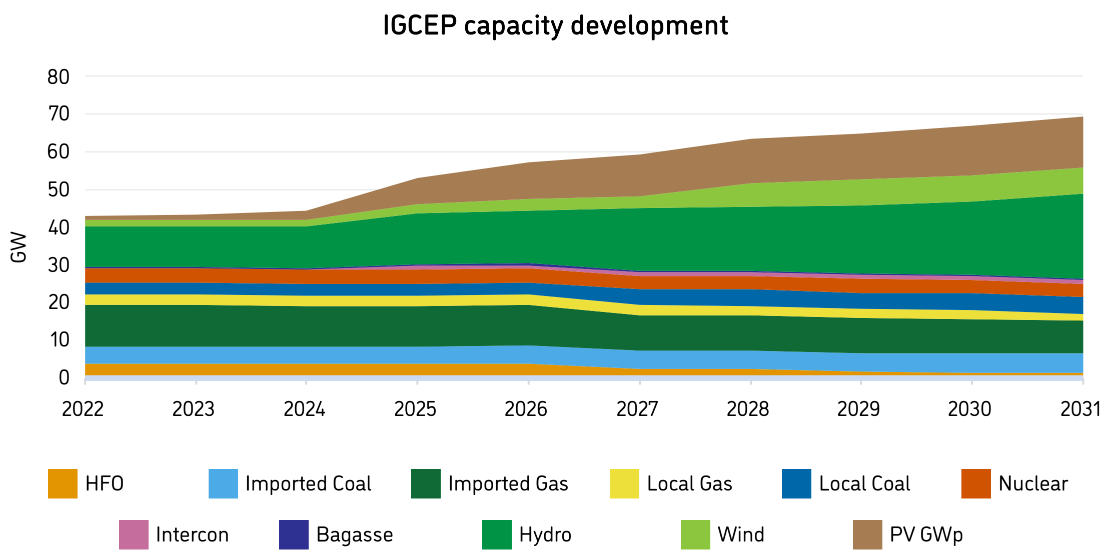
The optimal total amount of PV and wind plants that can be integrated into the grid depends on demand at the time of VRE production, cost competitiveness of VRE-supplied electricity (which determines their position in the "merit order"), and grid constraints or the cost of eliminating grid bottlenecks and stabilization. The demand analysis has been performed for the 2028 planned grid for short-term opportunities and 2033 for long-term opportunities.

3.1 Demand

3.1.1 Pakistan Demand

The snapshot for 2028 and 2033 optimal least-cost capacity of VRE for the entire country is given in the IGCEP 2022. For 2028, NTDC forecasts 11.8 GWp of PV capacity in 2028 and 13.7 GWp in 2031, without specifying in detail the potential sites. For wind energy, a 6.9 GW capacity has been optimized in the base case of the IGCEP 2022 for 2031. This provides a large window of opportunity for VRE development in Balochistan, especially as the sites are to be selected using the least-cost method.

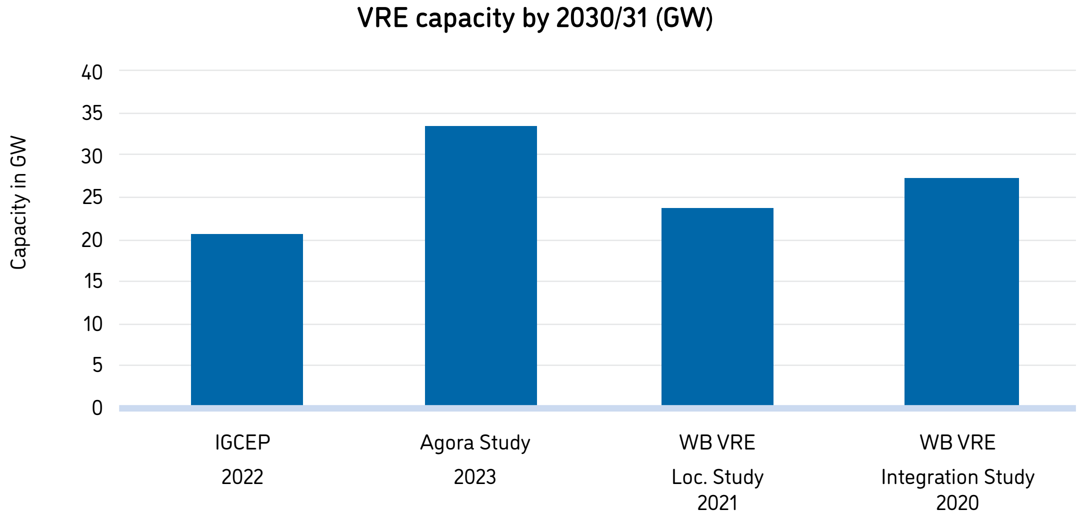
Figure 3.1: IGCEP 2022 capacity development



A special PV initiative by the government of Pakistan—the Special Task Force—has been initiated to install additional PV plants in the short run to reduce dependence on expensive energy generated through oil, gas, and coal plants.[18] The optimal share of VRE has been identified to be 40 percent considering all constraints (8.2, PPI, 2023).

18 *PM Shehbaz green-lights 10,000MW solar project to cut imported fuel use, DAWN News, September 1, 2022.*

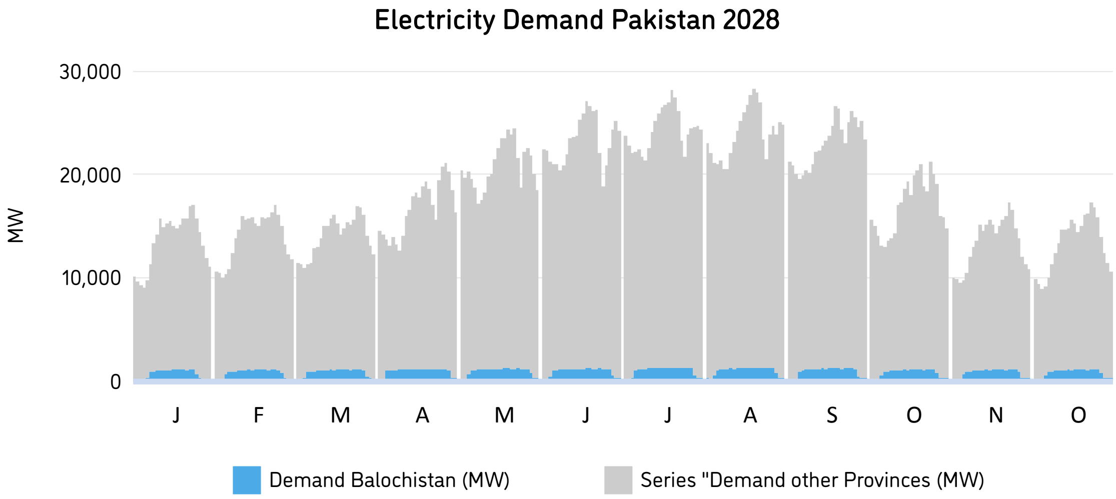
Figure 3.2: Optimal VRE capacity, other studies



Source: (8.2, PPI, 2023)

As per the IGCEP, by 2028 12 GWp of PV within Pakistan can be assumed. The locations are not fixed and will be selected by merit order as per National Energy Policy 2021.[19]

Figure 3.3: Low demand forecast, 2028, in hourly resolution



Source: IGCEP (NEPRA, 2022)

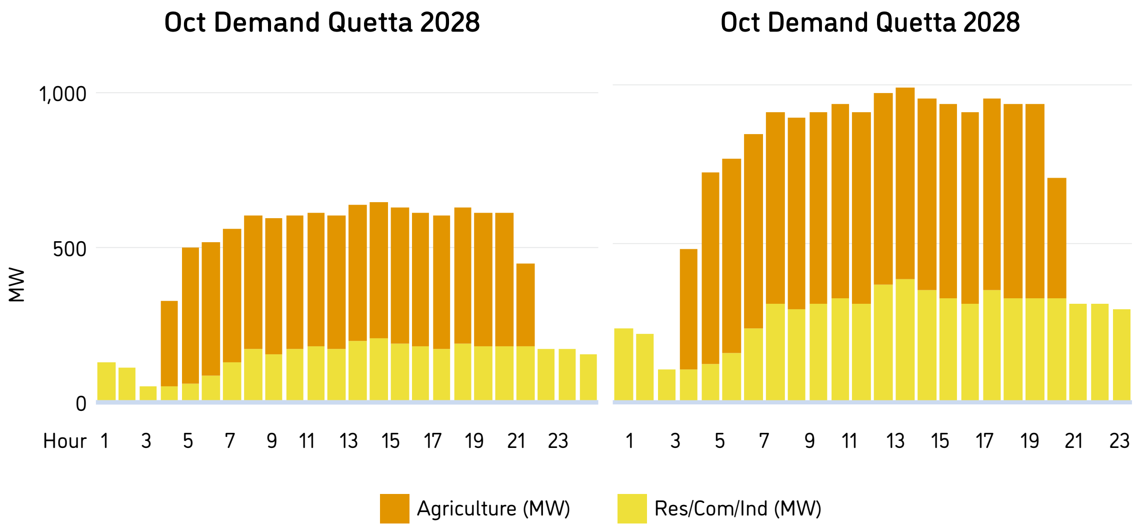
19 "Expansion in generation capacity shall be only on competitive and least cost basis (except for strategic projects, for which: (a) the qualification and methodology shall be provided in the National Electricity Plan, (b) the Government, in consultation with the Provincial Governments, shall approve such projects on case-to-case basis and (c) the relevant sponsoring Government / Provincial Government shall provide the funding to bridge the incremental cost (beyond least cost) of any such project." (MoE, Power Division, 2021).

3.1.2 Regional Demand Analysis

Monthly regional demand aggregated by division for Rakshan, Makran, Kalat, Quetta, and the eastern divisions (as they are very similar in nature) has been provided by QESCO (QESCO, 2021) for 2028 and 2032. Based on the data provided, the demand until 2033 has been derived. An hourly load forecast has been modeled based on QESCO-given parameters of regional, monthly, and peak loads in order to rationalize the demand with VRE supply. The demand profile for agricultural users was taken from a detailed demand analysis based on 250 agricultural sites and their irrigation requirements based on cropping patterns (NESPAK, 8p2, 2020); the underlying assumption was always that by providing incentives, the demand for irrigation could be shifted to daytime hours, aligning it with the solar generation profile.

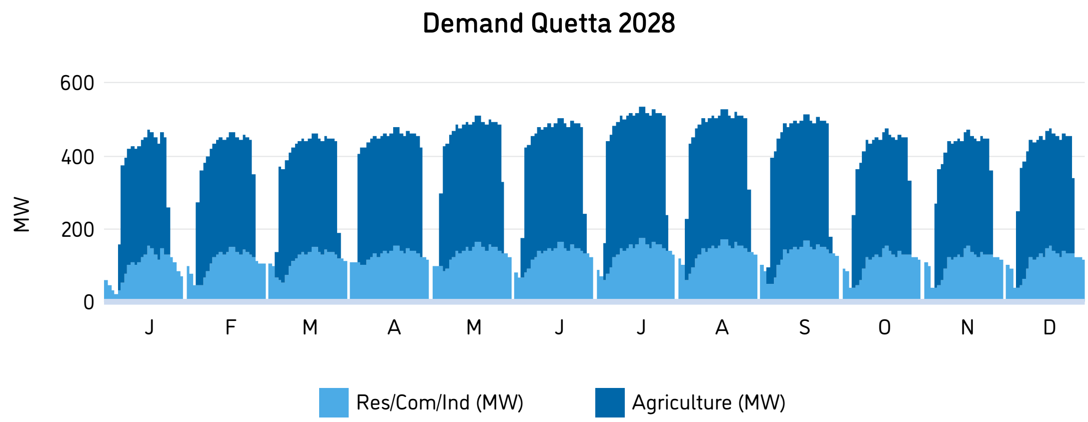
The following graphs show the results of the hourly demand estimation for the Quetta division in October 2028 and 2033. For sensitivity analysis, a low-demand forecast was also considered.

Figure 3.4: Demand modeling, October Quetta example



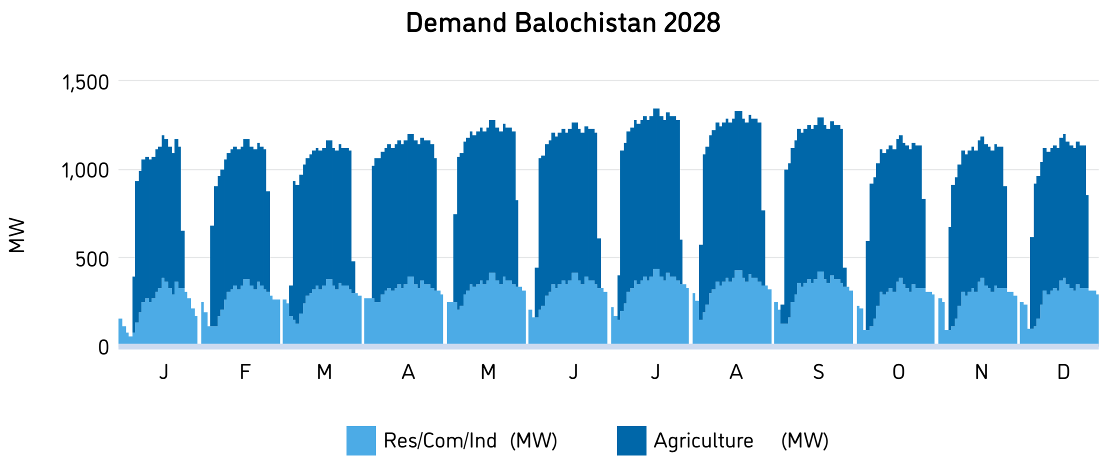
The Quetta division demand analysis for the entire year is shown in the figure below. In the Quetta division, energy demand is high due to irrigation requirements during the daytime; conversely, demand is lower at night. Interestingly, there is not a significant increase in summer load for air conditioning as observed in the Punjab or Sindh provinces. This is probably a consequence of comparatively less income, and fewer urban and industrial power users, as well as lower summer temperatures in densely populated areas.

Figure 3.5: Demand modeling, Quetta 2028



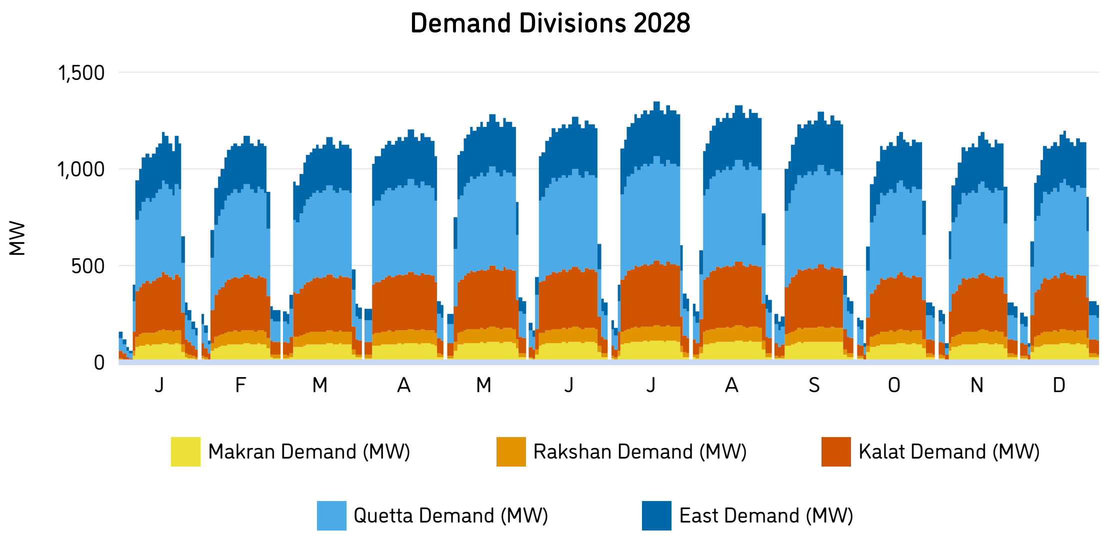
The other divisions in Balochistan reveal a similar trend, but at different levels based on a division's population and farming requirements. The figure below shows the demand of all divisions for 2028 by different consumer segments.

Figure 3.6: Demand modeling, Balochistan, by customer segment 2028



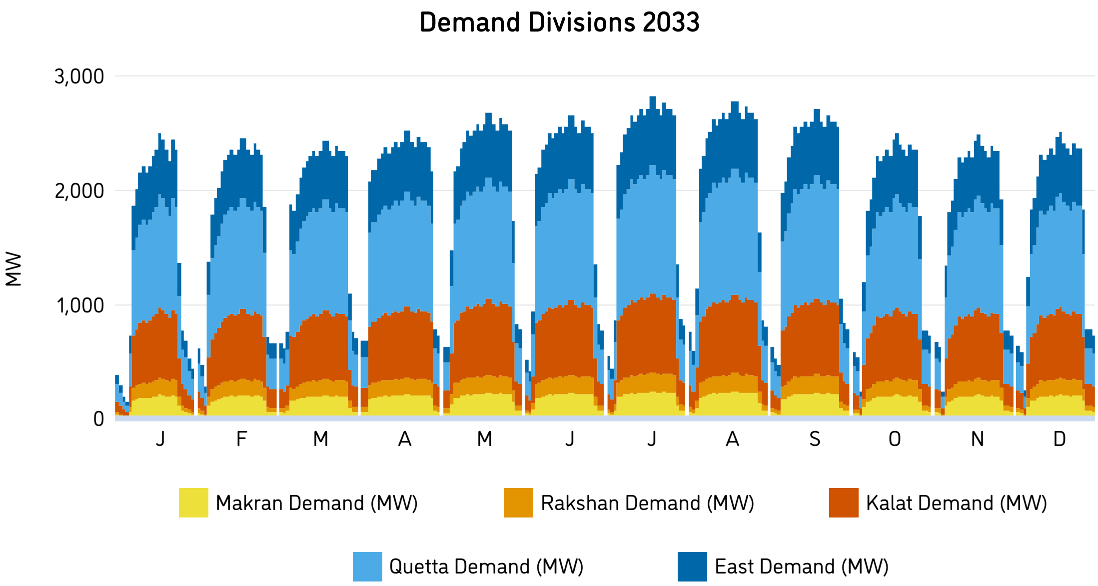
The magnitude of demand in each division is shown in the figure below. Quetta has the highest demand, and Rakhshan and Makran lag behind because of their low population. As mentioned, all the divisions share a similar profile.

Figure 3.7: Demand modeling, Balochistan 2028 low forecast, Divisions



For 2033, the expected demand profile remains unchanged except for a 57 percent increase in the magnitude of demand. This is also valid for Gwadar, which is lagging behind its development plan.[20]

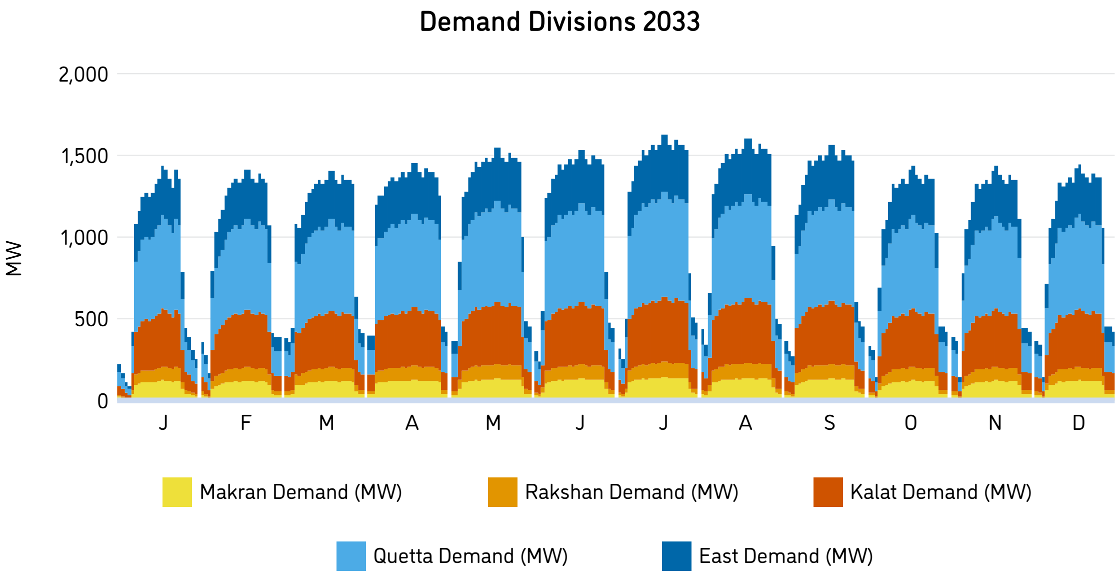
Figure 3.8: Demand modeling, Balochistan 2033, Divisions



The low-demand forecast for 2033 is 45 percent lower that the expected demand, which is a significant variation and has been used for risk analysis.

20 "The load forecast of QESCO for the base year 2020-21 compared with load demand of Gwadar Development Authority (GDA) based on study conducted in 2016, in which they projected that Gwadar load as 500 MW approx. in 2021 but its actual load demand is about 20-30 MW, as already forecasted by QESCO. A series of meetings / correspondences have been carried out under the supervision of NTDC to ascertain realistic future demand of Gwadar & Makran Areas of Balochistan." (QESCO, 2021), p. 15.

Figure 3.9: Demand modeling, Balochistan 2033, Divisions, low forecast



3.1.3 Additional demand – Mining

As the major industry in Balochistan, mines present a future potential demand under VRE demand and analysis. Most of the current electricity demand of the mining industry (that is, approximately 63 MW) is supplied by HFO or locally available crude oil. The major mining activities are currently located in the Rakshan division and Chagai area. The existing major copper and gold mine of Saindak presents a peak load of 50 MW whereas other small mines including those for coal, barite, and other minerals consume only 13 MW of peak power.

An upcoming mining operation at Reko Diq (copper and gold) is another site of potential VRE demand. In the projected scenario for 2028, the Reko Diq mine is expected to have a peak load of 150 MW, and the current mining load of 63 MW brings the total load to 213 MW. Accounting for potential contingencies related to the mining of other minerals, it is estimated that the overall mining load for 2028 could reach approximately 226 MW. This was computed using data from the mines and minerals department of Balochistan based on the energy needed per extracted ton of the aforementioned minerals. In the near future, Reko Diq will require 300 MW of peak load in the same vicinity. This energy requirement of the division can be met by VRE to a great extent.

According to a 2022 study by Deloitte[21] energy is one of the biggest expenses for mining companies, constituting approximately 30 percent of total cash operating costs, therefore the rewards of shaving off even a fraction of energy usage can be considerable. Although no mining site in Pakistan uses VRE for energy generation yet, it has been tested successfully across the globe.[22] Already in 2011 Barrick Gold completed its $50 million Punta Colorada wind operation, making it the first wind farm built by a mining company in Chile. Since then Barrick is using RE energy for its mines.

Based on the study by Deloitte and also the case studies in Pakistan performed for this assignment, miners have the opportunity to drive down energy costs by up to 25 percent in existing operations and 50 percent in new mines. As mines are usually off-grid in challenging environments the economics will be very similar for Solar PV. For electricity from wind it depends on the wind resources at site and the logistics and other costs of installing the towers. Clearly this is highly dependent on the location; meanwhile, however, in the Chagai area the wind resource is excellent.

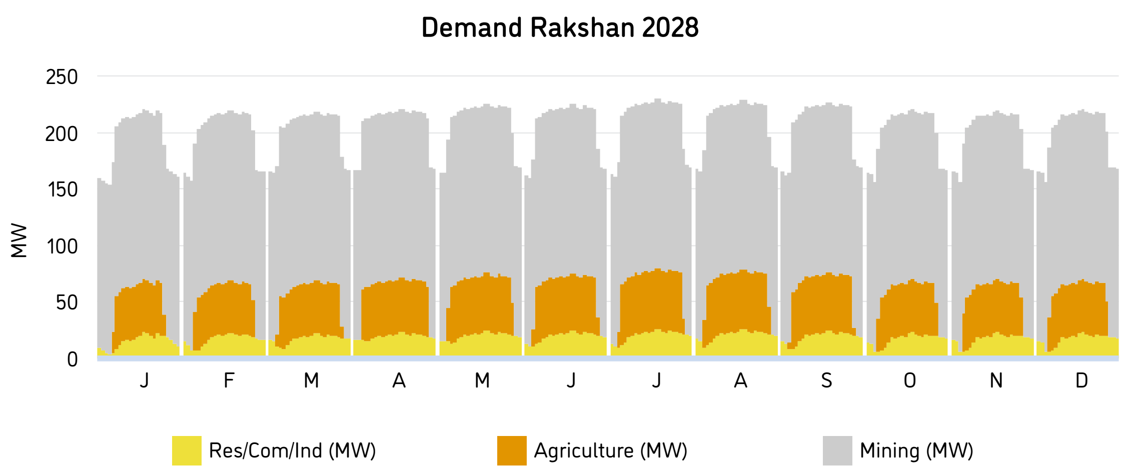
21 Deloitte, 2017, Renewables in Mining: Rethink, Reconsider, Replay.
22 Resource World Magazine, 2020, Mining companies successfully switching to renewable energy

Table 3.1: Peak load calculation for mining in Balochistan

tSN	Mineral type	Extracted ton/ (6 months)	Energy required/ ton (kWh)	Peak load @ 0.6 load factor (KW)
1	Reko Diq Gold/Copper	80,000	5,150	150,000
2	Saindak Gold/Copper	10,000	8,800	50,000
3	Coal	1,764,252	1	570
3	Marble	955,577	3	1,092
4	Limestone	2,914,408	2	1,663
5	Iron ore	881,511	25	8,385
6	Chromite	91,692	30	1,047
7	Barite	78,186	9	268
8	Granite	2,118	2	1
9	Copper	1,070	20	8
10	Basalt	15,748	3	18
			Total peak kW	213,052

The extrapolated demand from mining in Rakshan division on an hourly basis was added to the provincial demand profile. The following example for Rakshan shows high energy demand by the mining sector.

Figure 3.10: Demand modeling, Rakshan 2028



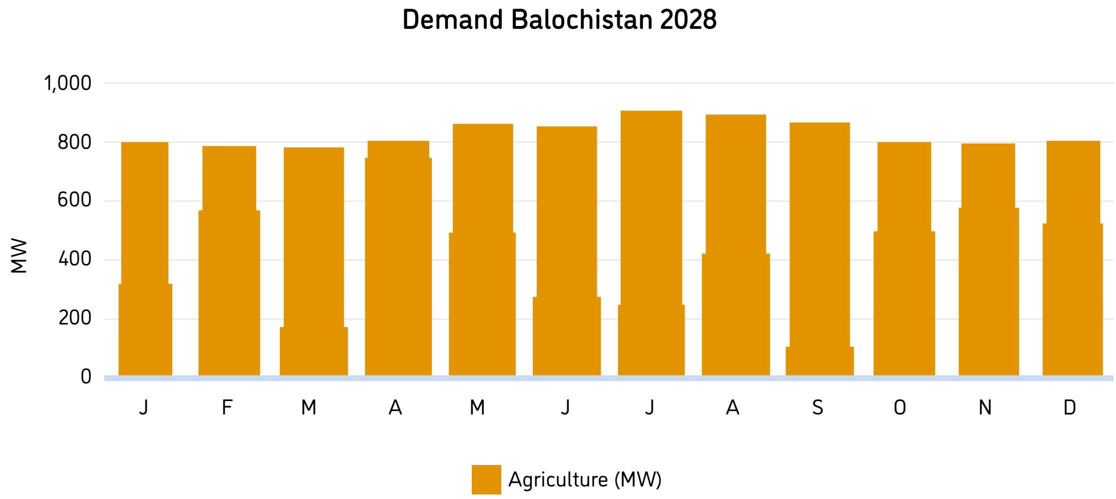
In addition to mining, regional demand in industrial zones like Gwadar could potentially exceed the QESCO forecast. However, at present, there is no substantial basis on which to make such a conclusion, so this study does not pursue the topic.

3.2 Demand reduction through improved efficiency and distributed PV

As mentioned earlier, most of the current demand in Balochistan is from agriculture tube wells. The expected demand scenario assumes a 7,482 GWh demand in 2028 for tube wells. This seems unrealistic, given the current supply and payment problem, and it is unlikely that electricity demand from tube wells would increase by 5,100 GWh. Accordingly, the low-demand scenario for tube wells in 2028, with 5,472 GWh gross, is used as a base assumption. However, if the government of Balochistan or the federal Ministry of Energy decides to address the problem of electricity supply with 1.3 GWp (75 percent of maximal) DPV deployment following the findings of the feasibility study commissioned by the NTDC (NESPAK, 8p2, 2020), then remaining gross demand would fall to 2,792 GWh in 2028. This would be a significant variation which could increase the provincial VRE surplus production to be exported to the rest of the country. Details and background can be found in Consultant's Report on Distributed PV.

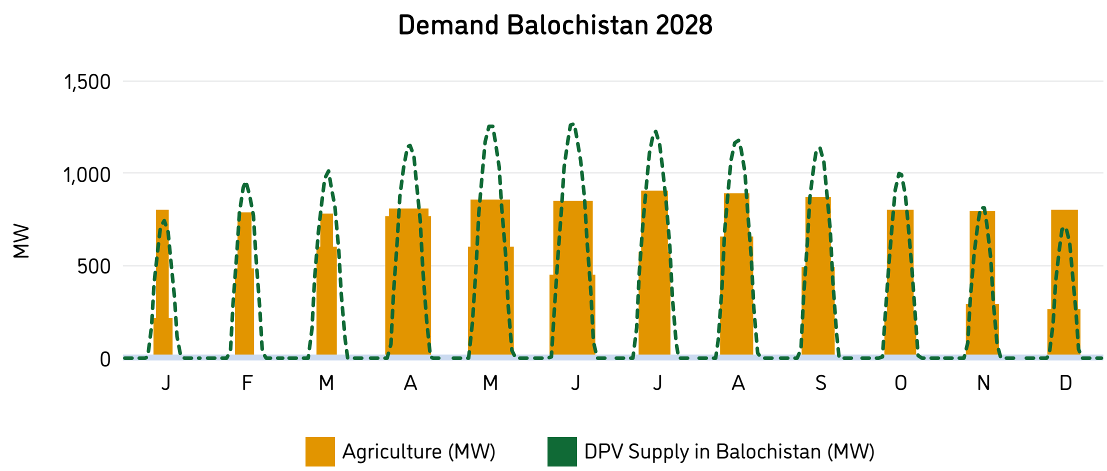
The following two figures illustrate the demand reduction implication of the potentially maximum of 1.7 GWp DPV.

Figure 3.11: Gross monthly demand of agriculture tube wells in current conditions



DPV deployment would have two effects: it would lead to loss reductions in the transmission network, which will in turn reduce gross demand; and it would also deliver electricity locally, which will further reduce the net electricity demand. With 1.7 GWp of DPV the annual agricultural demand could be met.

Figure 3.12: Gross monthly demand of agriculture tube wells with DPV supply



3.3 Electricity grid analysis and Export to other Provinces

In the IGCEP 2022, 20 GW of wind and PV electricity is expected to be installed by 2031. By 2033, it is likely to increase to 22 GW or more as the IGCEP 2022 returned lower VRE volumes than other studies based on the same assumptions. Of this total, 2 GW is represented by existing wind installations in Jhimpir area, and about 2 GW by already installed PV projects. Furthermore, an estimated 2 GW of distributed generation has been deployed under the net metering regime. Thus, overall, about 16 GW remains amenable to least-cost supply according to the National Electricity Policy of Pakistan 2021 (MoE, Power Division, 2021).

In the grid model of 2028 developed under this study, cross-border transmission capacities to the other provinces of Pakistan have been analyzed to estimate the maximum VRE export from Balochistan to Pakistan on the existing grid.

By adding and simulating the suggested PV potentials (alternating current: AC) at the nearest 132kV QESCO grid locations, the capacity of 132kV lines in the NTDC 2028 model used a ceiling with a 20 percent safety margin. After adding PV capacity as per the WB locational study it was observed that the load profile as well as the 132kV and 220kV transmission line capacities of the QESCO and NTDC network in the 2028 model were well matched and had sufficient space for additional capacity if needed. Accordingly, the system remained under safe operational limits. Moreover, further space for inserting more PV capacity was found at 220kV Zhob-DIkhan, Loralai-DGKhan, Uch-Shikarpur, Dadu-Khuzdar, 132kV Rakhnai-Sakhisarwar, and Hub-KKI transmission line interconnections. Maximum VRE production at any time is capped at a cumulative cross-border capacity of about 2.7 GW in 2028. For more information, see Table 3.2: Transmission Line MW Export Capacities from Balochistan to Rest of Pakistan.

Initially, PV capacities (in AC) were added as per the locational study at the nearest available 132kV/11kV substation points. The remaining unutilized potentials on relevant 220kV or 132kV transmission lines were then used to identify new PV sites in the QESCO and NTDC grid network.

Based on relevant transmission line electrical parameters (that is, line resistance, line inductive reactance, and line capacitive reactance), the SIL[23] was calculated and used to find limits in MW as per the St. Clair Curve based on length. Medium- and long-length transmission lines were put under safe loading conditions based on their SIL Limits. For short-length transmission lines, 80 percent of the thermal loading limit of the relevant transmission line was used to maintain safe operational limits.

Further, since PV capacities have been introduced in the network, for maintaining the supply & demand balance the operating capacities of thermal plants (that is, Uch I, Uch II, Guddu, Aveli Bahadur Shah Bhikki, and Andalloki) and HPPs (that is, Tarbela) were therefore reduced in peak hours. The hydroelectric discharge reduction is for a few hours only during the day to avoid affecting the criteria of waterflow for irrigation from the dam.

It was found that the 220kV Uch-Shikarpur line is the main transmission line interconnection between Balochistan and other parts of Pakistan and is currently being used for the Uch power plants (located in Uch D.M. Jamali Balochistan). The Uch power plants (Uch I 586MW and Uch II 404MW) are high in the merit order in the NEPRA State of Industry Report 2022, being one of the cheapest power generation plants. Therefore, constraints in running Uch power plants at their minimum operating limits in the daytime will be a bottleneck for the maximum export of Balochistan PV potential. The power purchase agreement (PPA) of the Uch I power plant has a 30-year term and was commissioned on October 18, 2000 (that is, seven years remain on the PPA contract as at 2023). Since the Uch I PPA is expected to expire in 2030, its associated transmission network can be considered in the 2033 case scenario. The PPA for Uch II will expire in 2039.

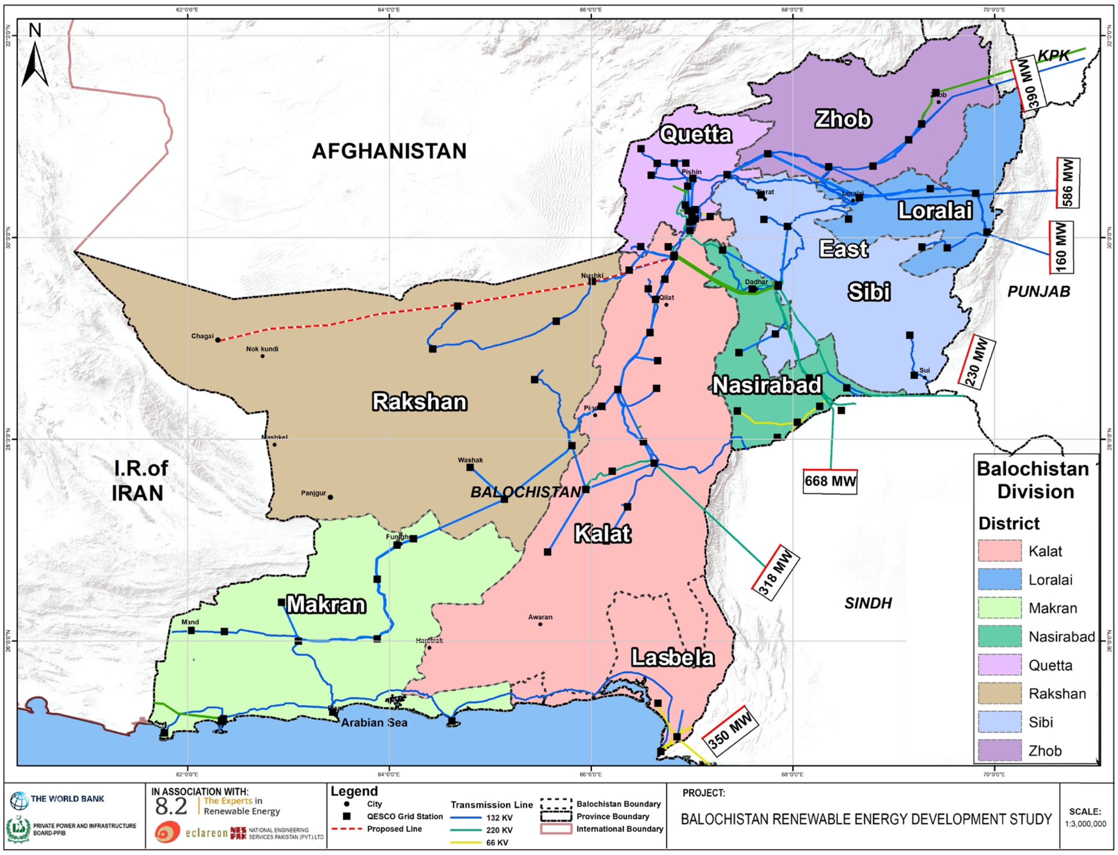
The table below shows safe loading limits for the transmission lines allowing for maximum export from Balochistan to the rest of the country.

23 Surge impedance loading (SIL) is transmission line loading condition (unit—MW). The condition is used by system operators as a benchmark to determine whether a transmission line is acting as a capacitance that injects reactive power into the system or as an inductance that consumes reactive power, thus contributing to reactive power losses in the system.

Table 3.2: Transmission Line MW Export Capacities from Balochistan to Rest of Pakistan

Transmission Line Description	Length (km)	Capacity (MW)[24]
Zhob-DIKhan 220kV Double Circuit Single Conductor ACSR Rail	211	390
Loralai-DGKhan 220kV Double Circuit Twin Bundle ACSR Rail Conductor	200	586
Uch2-Shikarpur 220kV Single Circuit Twin Bundle ACSR Rail Conductor	95	428
Uch1-Shikarpur 220kV Single Circuit Single Conductor ACSR Rail	158	240
DMJamali-Guddu 220kV Single Circuit Single Conductor ACSR Rail	168	230
Dadu-Khuzdar 220kV Double Circuit Single Conductor ACSR Rail	300	318
Rakhnai-Sakhisarwar 132kV Double Circuit Single Conductor ACSR Lynx	67	160
Hub-KKI 132kV Double Circuit Twin Bundle AAAC Greeley	16	350
Total Transmission Network Export Capacity from Balochistan[25]		2,702

Figure 3.13: 2028 grid model visualization, including export capacities from Balochistan to rest of Pakistan



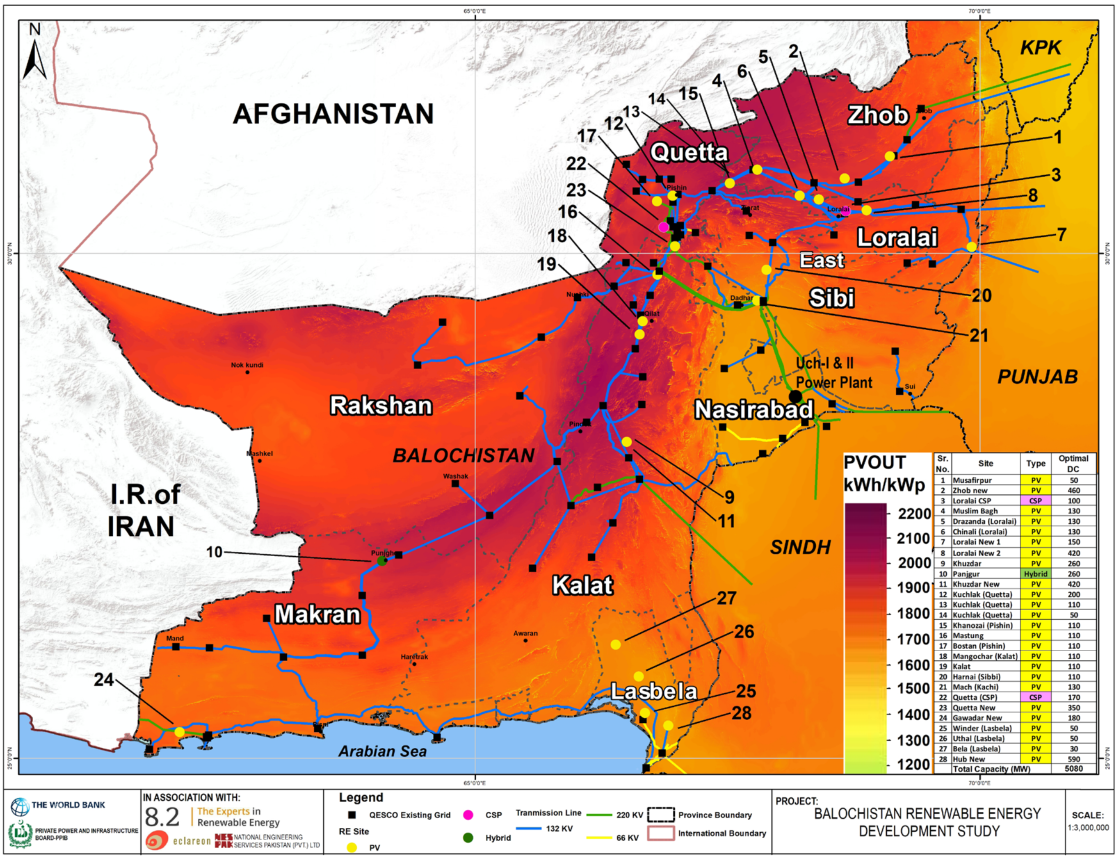
24 Per line length.
25 It is assumed that in daytime the Uch I and Uch II power plants will be operating at their minimum, allowing more PV power to be exported from Balochistan to Pakistan. Moreover, the export potential has been calculated based on transmission line lengths without considering N-1 contingency conditions to maximize the export of PV power.

4. Short-Term Options until 2028

4.1 Utility-Scale Plants

As mentioned earlier, the current study makes use of the previous analysis performed under the World Bank VRE Locational Study (2021) as a foundation and explores the grid slots and land availability in more depth for short-term (until 2028) utility-scale projects. QESCO and IGCEP 2022 data serve as reference for modeling the energy demand and supply in this respect. The output of this exercise can be viewed as potential utility-scale projects, overlaid on a PV energy output map (see figure below). The sites are in line with the TSEP 2028 plan. Up to 5 GW of RE projects can be developed using the existing and planned infrastructure, including 132 kV and 220 kV lines.

Figure 4.1: Identified utility-scale VRE sites



4.1.1 Identified Opportunities

In the short term, 2.5 GW of aggregated PV and wind sites have been identified in the VRE Locational Study in preferred Scenario 3 (World Bank, 2021) as listed in Table 4.1 below, considering the existing grid infrastructure. Scenario 3 is used here because it selects the lowest cost sites from other scenarios under the VRE Locational Study and then again ranks them by financial attractiveness as a scaled measure of the expected cost from an opportunity. The scale is 10 for US$ 4cts/kWh to 0 meaning US$ 10 cts/kWh. In this scenario the explicit target of 20 percent (2025) or 30 percent (2032) 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, resorting to 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 VRE targets of 20 percent and 30 percent.

Table 4.1: Proposed PV sites in Balochistan by World Bank VRE Locational Study

SN	Location	Technology	Capacity (MWp)	Year	Financial attractiveness	Expected PPA rate US$ cts/kWh
1	Kuchlak	PV	200	2023	9.74	4.17
2	Panjgur	PV	254	2023	9.58	4.26
3	Chinali	PV	132	2023	9.29	4.44
4	Khuzdar	PV	244	2023	9.24	4.47
5	Muslim Bagh	PV	132	2023	9.12	4.54
6	Khanozai	PV	120	2023	9.11	4.55
7	Drazanda	PV	132	2023	9.10	4.55
8	Kalaat	PV	120	2025	9.08	4.56
9	Manochar	PV	120	2025	9.05	4.58
10	Hernai	PV	120	2025	8.92	4.66
11	Mastung	PV	120	2023	8.87	4.69
12	Loralai	PV	50	2025	8.54	4.89
13	Musafirpur	PV	50	2025	8.53	4.89
14	Chagai 25	PV	250	2025	8.23	5.07
15	Hub	PV	210	2023	7.86	5.29
16	Mach	PV	132	2023	7.72	5.38
17	Boston	PV	130	2023	7.69	5.40
	Total		2,516			4.70

Source: VRE Locational Study (World Bank, 2021)

In comparison to national plans, up to 2023, only 650 MWp of PV plants have been considered by PPIB for auctioning. The NTDC has considered only 1,100 MW until 2028 under the TSEP.

For this study, an additional 2.2 GW has been identified without the need for grid enhancements using additional lines and sites, and the opportunities were evaluated for their expected energy yield, installation cost (including grid connection), and expected price of electricity. The table below summarizes the updated and new locations. The expected costs have slightly decreased as a result of reduced capital expenditure (CAPEX) assumptions. An example of this evaluation is provided in the form of a case study for the Kuchlak site in the section 4.1.2 (Case study 1 - Utility-Scale PV). Further PV locations mentioned in this table were also analyzed for the utility-scale PV plants and snapshots of analysis are also available in Consultant's report: Detailed Analysis of Utility-Scale Opportunities.

Table 4.2: Identified actual VRE sites for existing grid

SN	Location	Technology	Capacity (MWp)	Year	Expected PPA rate US$ cts/kWh
1	Musafirpur	PV	50	2023	4.76
2	Zhob new	PV	460	2025	4.61
3	Muslim Bagh	PV	130	2023	4.62
4	Darazanda	PV	130	2025	4.63
5	Chinali	PV	130	2023	4.62
6	Loralai new 1	PV	150	2023	4.70
7	Loralai new 2	PV	420	2023	4.44
8	Khuzdar 1	PV	260	2023	4.45
9	Khuzdar 2	PV	420	2023	4.34
10	Kuchlak portfolio	PV	360	2023	4.25
11	Khanozai	PV	110	2023	4.51
12	Mastung	PV	110	2028	4.55
13	Bostan	PV	110	2023	5.68
14	Quetta New	PV	350	2023	4.10
15	Mangochar	PV	110	2023	4.50
16	Kalat	PV	110	2023	4.47
17	Hernai	PV	110	2023	4.68
18	Mach	PV	130	2023	5.66
19	Hub New	PV	590	2023	4.90
20	Lasbela	PV	140	2023	5.43
21	Panjgur	PV	260	2023	4.44
22	Gwadar	PV	180	2023	4.85
	Total		4,820		4.60

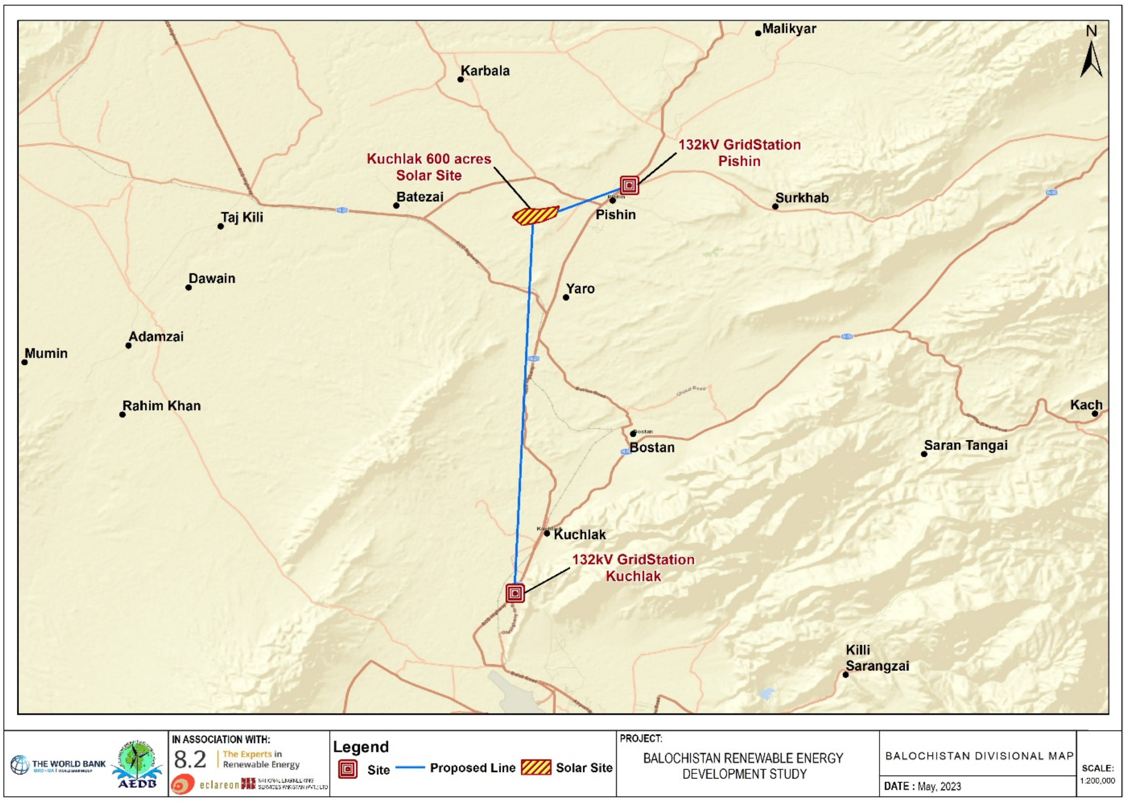
4.1.2 Case study 1 - Utility-Scale PV

This case study is presented for a proposed utility-scale PV plant in Kuchlak Site as an illustration of how one of the suggested utility-scale PV plants could potentially be designed.

Kuchlak Site Characteristics

The site is located north of Kuchlak city at Latitude 30°34'12.71"N and Longitude 66°57'24.50"E, approximately 28 km away from Kuchlak city and 6 km from Pishin—these are the respective distances to the available grid. The area is mostly barren, consisting of rocky soil with low vegetation as can be seen in the figure below. Covering roughly 567 acres (229 ha), the Kuchlak site is accessible from Karachi via N65 (distance 895 km), though the ownership of the land and presence of settlement need to be confirmed by the government of Balochistan.

Figure 4.2: Kuchlak area, Balochistan



Sizing of System

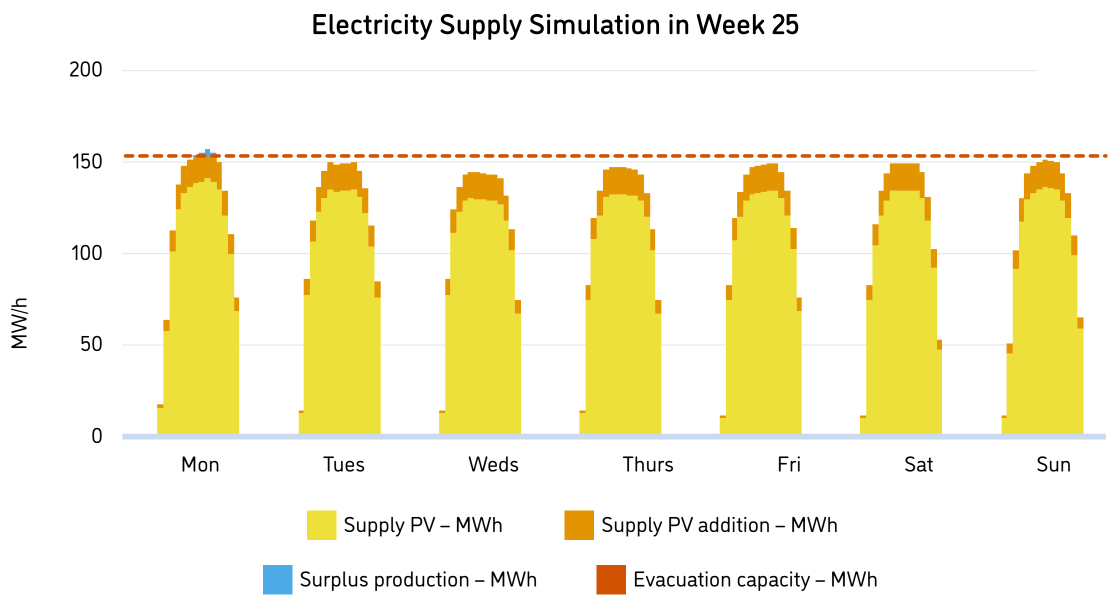
Kuchlak site capacity size is estimated to be 180MWp (NTDC, 2022), however analysis is done based on an optimal size of 200MWp. The proposed sizing of the system considers the technical parameters in table 4.3 and determines how much capacity will be installed and how well the grid capacity will be used. The figure 4.3 illustrates the effect of the proposed sizing (referred to in that figure as supply PV addition) compared to traditional sizing of a system (supply PV) to a ratio of 0.8 AC to DC to avoid any curtailment[26]. In the proposed sizing the grid evacuation capacity is utilized optimally for the least cost of evacuated electricity. This allows a curtailment for a few hours in the year for a significant increase in total evacuated electricity.

Table 4.3: Technical characteristics, Grid utilization factor and annual output

Category	Unit	Information
Plant size (NTDC TSEP)	MWp	180
Plant size (optimized)	MWp	200
Technology		Bifacial Crystalline Silicon (PV)
Orientation		Tracking N-S
Annual output at proposed size and site	MWh/a	458.29
PV plant capacity factor (DC)	%	26.15
Grid utilization factor	%	34

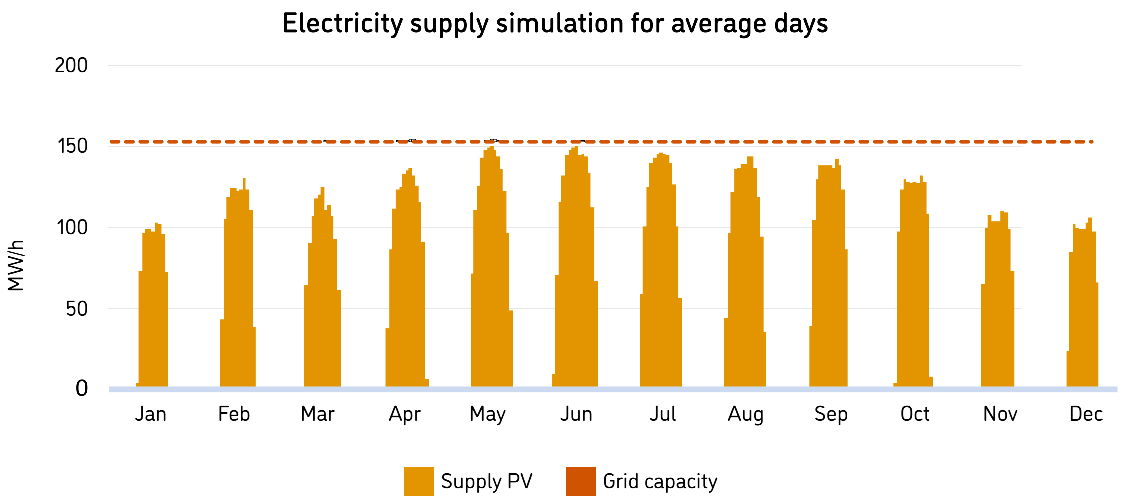
26 limiting generation or transmission of solar power for economic or grid-capacity reasons..

Figure 4.3: Example output of proposed sizing versus conventional sizing during the peak supply time in the month of June



The following graph illustrates the average hourly output per day of each month. The electricity output fits well into the maximum grid capacity with the proposed sizing.

Figure 4.4: Seasonal profile: average simulated day in a month



Economic Evaluation

Depending on the merit order, it can be cost-effective to implement some level of curtailment. In this study, US$0.08/kWh was assumed as the alternative cost of electricity for long-term HPPs. Under this assumption, a curtailment of 50 percent for the additional marginal PV generation, costing US$0.045/kWh, would result in the most cost-optimal sizing. This effect is illustrated in the table below. The proposed sizing has an expected PPA price of US$0.0437/kWh, while the maximum sizing case yields a higher net present value (NPV) for CPPA and greater savings in the initial years. However, if more PV systems compete on evacuation space at other points at the same grid (notably causing potential bottlenecks for exports to other parts of Pakistan), a maximum sizing for individual plants might not be sensible. A summary of economic results is shown below.

Table 4.4: Economic results

Economic output	Proposed sizing	Conventional sizing	Maximum sizing
PV MWp	200	180	220
Production surplus %	0%	0%	2%
Initial year RE GWh/a	468	421	504
RE grid utilization %	35%	31%	38%
CAPEX (US$, millions)	128	118	140
OPEX (US$, millions/year)	72	75	69
RE PPA cts/kWh	4.37	4.48	4.46
GHG reduction Mt CO_2	8.2	7.4	8.8
NPV vs. HPP CPPA (US$, millions)	194	172	206
Initial year savings (US$, millions)	17	15	18

4.1.3 Case Study 2 – CSP

Sample Plant Description

The following table shows the parameters of a sample CSP plant that could be built in Balochistan. CSP is location-limited due to available resources (DNI). A size of 100 MW CSP has been selected—a lower plant size would not be conducive to economies of scale and thus increase the levelized cost of electricity. However, a GW-scale project would be challenging to be implemented in Pakistan in terms of risk and investment, being the first of its kind in Pakistan.

The CSP plant has been designed here to provide stable electricity dispatch during the evenings and at night, which is its primary advantage over PV and wind power plants. It is highly recommended to combine the CSP plant with PV on the same site to generate daytime power and consequently reduce the overall expected cost of electricity, similar to the projects in Morocco and Dubai shown in the subsequent section. However, the evaluation conducted in this study focuses solely on the CSP component, excluding the PV integration.

Table 4.5: CSP sample plant parameter overview

Parameter	Value	Comments
Technology	Tower or parabolic trough	Several pros and cons for both tower (higher efficiency, higher complexity) and trough (easier deployment and scalability).
Size	100 MW CSP	Much smaller sizes would not be economical; higher sizes increase the overall financial risk.
Location	North of Quetta or Kalat region	Location limited due to available resource (DNI). See ANNEX A: CSP Technology.
Design	For evening and night-time dispatch	Daytime dispatch through CSP would also be possible; however, for covering daytime power, a combination with PV is the better option—this part is excluded from the analysis.
Cooling	Dry cooling	Dry cooling for lower water consumption; see Annex A.
Water consumption	Approximately 180,000 m^3 per year	Water consumption for dry cooling of this plant[27] based on the estimated annual CSP production. Additional water is required for mirror and panel cleaning, but the volume is comparatively negligible.
Storage	14h for evening and night usage	During 8:00–16:00, PV would be the best option for co-generation on the same site. CSP would deliver stable output from 16:00–6:00, for example (can be controlled in tender process and operation). Higher amounts of storage are also possible but probably not required when PV is installed for co-generation.
CAPEX	About US$500 to US$700 million	CAPEX would be US$550m based on a recent cost estimate of US$5,500 per kWp (World Bank, 2021).[28] However, due to remoteness, security issues, inflation and country risk, higher prices can be expected.
Possible PPA rate	US$0.07–0.10/kWh[29]	Estimate high uncertainty, see comments on CAPEX and in footnote, as well as Annex A.
Capacity factor	58%	Depends on amount of storage. Can be steered through tender documents. Amounts up to 90 percent are possible without a significant cost increase; here, a co-location with PV and focus on evening peak was assumed. In line with estimates by the International Renewable Energy Agency (IRENA , 2020).
Annual electricity production	510 GWh	Assuming 58 percent capacity factor of 100 MWp.
Annual CO_2 savings	410,000 tCO_2eq per year	Assuming a replacement of coal.[30] This is justified as CSP provides dispatchable power.

27 Details in ANNEX A: Concentrated Solar Power technology, 350 liters per MWh.
28 The global weighted-average total installation costs (CAPEX) of CSP plants commissioned in 2019 were US$5,774 per kWp. There is a high uncertainty range as there is no reference project in the region and the influence of country risks is hard to estimate. This number obviously depends strongly on the amount of storage included in the plant. However, this is not reflected in the cited report. In any case, most plants built in recent years have storage within the range of 7 to 12 hours.
29 Based on the results of the large-scale (close to 1 GW each) CSP–PV plants in Dubai (Noor 1) and Morocco (Midelt) from recent years which both achieved a PPA rate of around US$0.07/kWh. A factor driving down costs in Balochistan is a very good DNI of 2,500 kWh/m^2 (in the best areas), while factors driving costs up are the cost of finance, remote location, possible security issues, political risk factors, a probably smaller size, and lack of infrastructure. How these are handled will define how much the PPA rate increase will be compared to the reference of US$0.07/kWh.
30 Based on 0.8 t per MWh for coal.

Conclusions for CSP

The following can be concluded from the parameters discussed in the previous table:

- CSP is a technically feasible technology for Balochistan and the DNI at the best spots (north of Quetta and Kalat region) is quite high in comparison to international levels (for example, better than Dubai);
- The cost of CSP in Balochistan would be highly competitive at international level. However, its competitiveness with other energy sources in the power sector would depend on the bids received and how its benefits of stable dispatch during the evening hours are evaluated vis-à-vis the overall national power sector;
- The envisaged 100 MW CSP PV plant would require a CAPEX of more than US$500 million, leading to an estimated PPA price of US$0.07–0.11 per kWh (or more if developers require a high-risk premium);
- CSP could provide "baseload-like" power (covering the evening peak) for the energy mix in Balochistan. The capacity factor of such a CSP plant with about 14 hours of storage is around 58 percent (assuming an "evening-only" design for dispatch). The day load can be covered through PV technology, making CSP and PV technologies complementary; and
- The construction of such a CSP plant would generate higher levels of local employment than PV.

Challenges for CSP technology in Balochistan include:

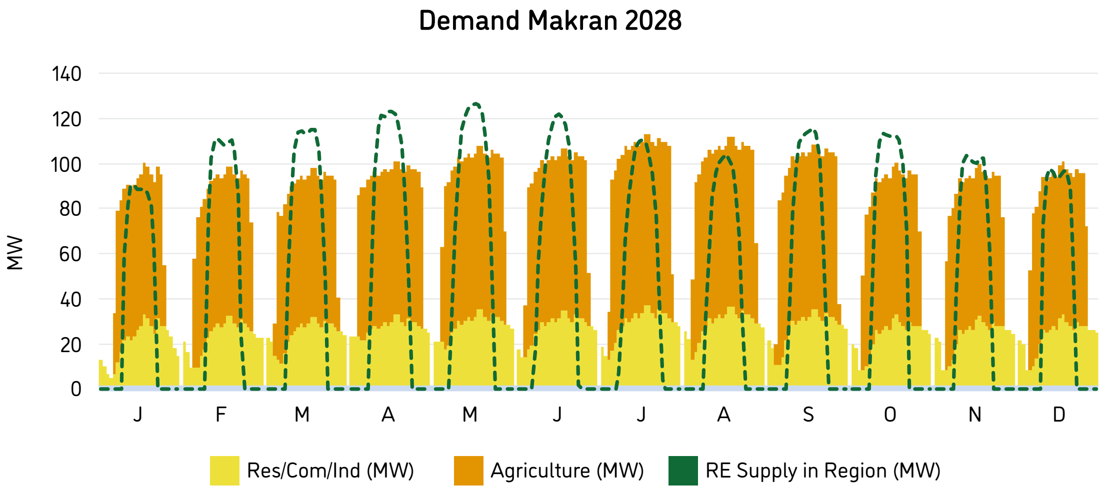
- Costs for import, logistics, and infrastructure development are higher compared to other less remote parts of the world where CSP projects are already being built (Dubai and Morocco, for example);
- The relatively high-water consumption requirement of CSP in the water scarce Balochistan region (about 180,000 m^3 per year for the 100 MW plant); and
- Political uncertainty in Balochistan might drive up finance costs.

4.1.4 2028 Supply–Demand Balance for Balochistan

Assuming that all identified utility-scale plants will be connected by 2028, the grid export capacity from Balochistan to the other provinces has been verified with the provided 2028 grid model. For this purpose, the local demand exceeding the supply of VRE was calculated at an hourly resolution. The local consumption pattern is a mix of industrial and residential as well as agricultural consumers. In the Quetta division, the proposed VRE production (from Kuchlak, Khanozai, Mastung, Bostan, Quetta New, and Mangochar) exceeds the industrial and residential loads. However, when considering the overall load, the VRE production aligns with the load distribution throughout the day, with higher generation during daytime and lower generation during nighttime.[31] As shown in figure 4.5, VRE from identified utility-scale plants for this region would be sufficient to meet local consumption requirements in the region (Quetta).

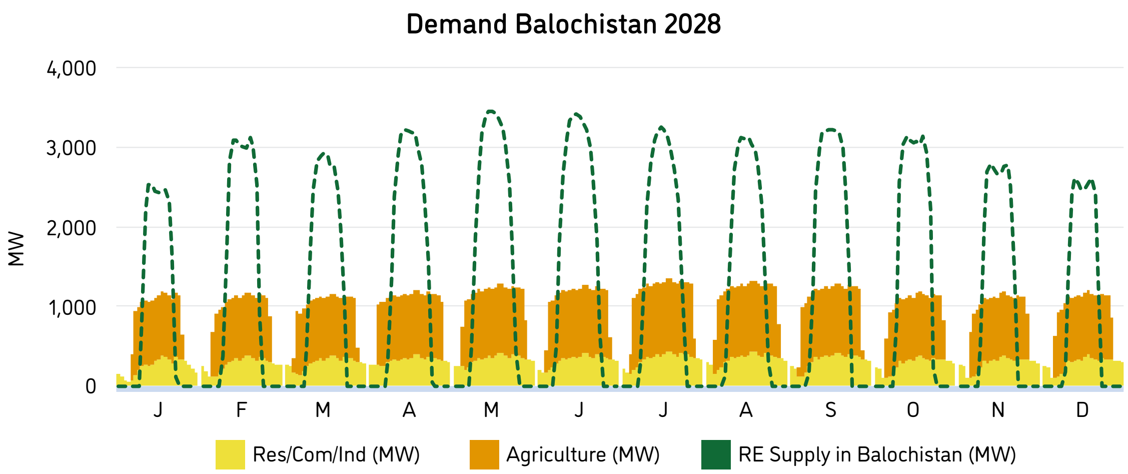
31 Assuming the agricultural load is moved to day instead of night.

Figure 4.5: Supply–demand balance, Makran region 2028



However, at the provincial scale in the low-demand scenario, the outlook is different. Especially in the eastern divisions, the potential VRE supply exceeds the total demand considerably and must be exported to other provinces.

Figure 4.6: Supply (low-) demand balance, Balochistan 2028



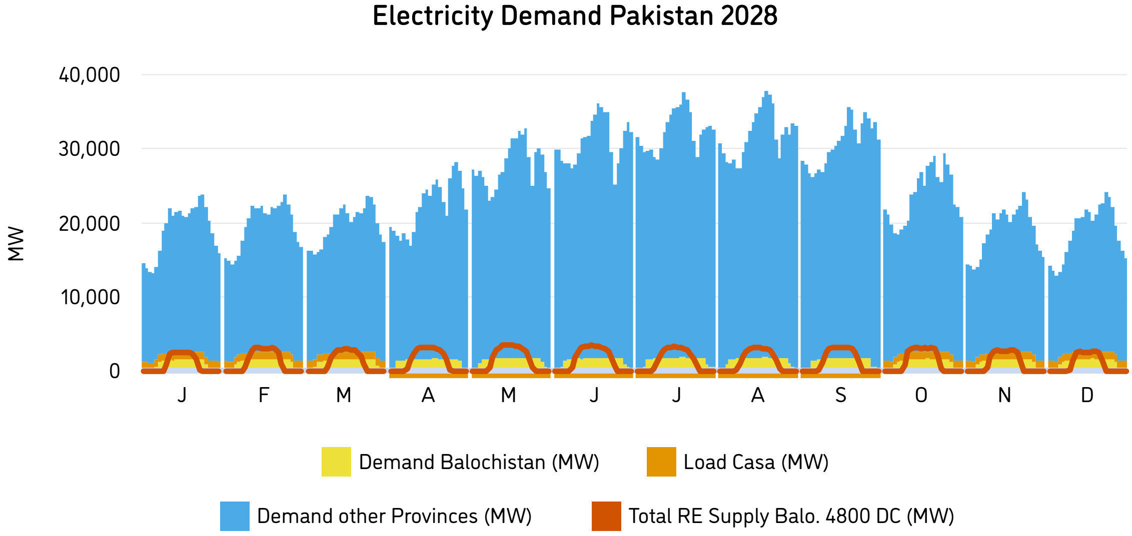
As long as the grid capacity is sufficient and VRE supply from Balochistan is at minimal cost, this scenario is optimal for Pakistan.

4.1.5 2028 Supply–Demand Balance for Pakistan

The additional RE supply would need to be exported to other provinces, as mentioned, unless international export occurs (international export is further discussed in Chapter 5.2).

Analyzing such export ability of Balochistan and the impact on the national demand, it is concluded that there is no near-term limitation that could collide with an ambitious VRE development in Balochistan but the VRE supply from Balochistan is relatively small (compare national peak demand in 2028—36 GW—to optimal peak VRE supply from Balochistan—5 GW). However, it would certainly be possible for Balochistan to supply an even more significant share of national demand, provided sufficient extra time were allowed for development of the necessary grid infrastructure.

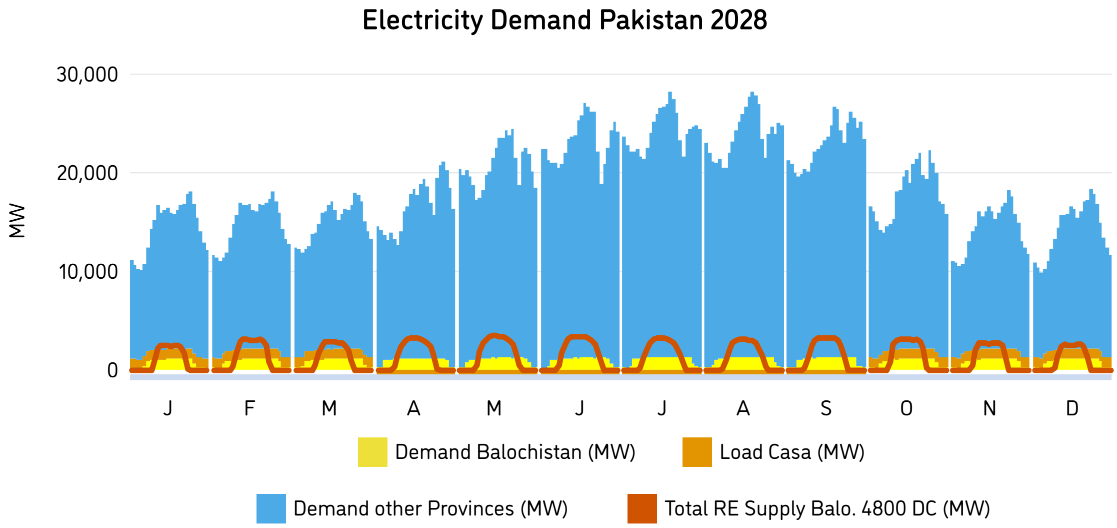
Figure 4.7: Impact of Balochistan export to elsewhere in Pakistan 2028 (expected demand)



Source: Demand data of IGCEP 2022

In the low-demand scenario, without international export, the VRE supply from Balochistan is small relative to national demand.

Figure 4.8: Impact of Balochistan export to elsewhere in Pakistan 2028 (low demand)



4.1.6 Grid Situation and Debottlenecking

The 2028 grid model was used to calculate the maximum capacity of suggested locations for utility-scale plants as well as the cross-border capacity for exporting electricity from Balochistan to other provinces. The maximum VRE production at any time is capped by Balochistan's total electricity export capacity to other provinces of around 2.7 GW in 2028, as shown above in Table 3.2: Transmission Line MW Export Capacities from Balochistan to Rest of Pakistan.

PV projects (having a defined AC power) were added as per the VRE Locational Study (World Bank, 2021) at the nearest available 132kV / 11kV substation points as a starting point. The remaining unutilized potential on relevant 220kV or 132kV transmission lines is subsequently used to identify new RE sites in the QESCO and NTDC grid network.

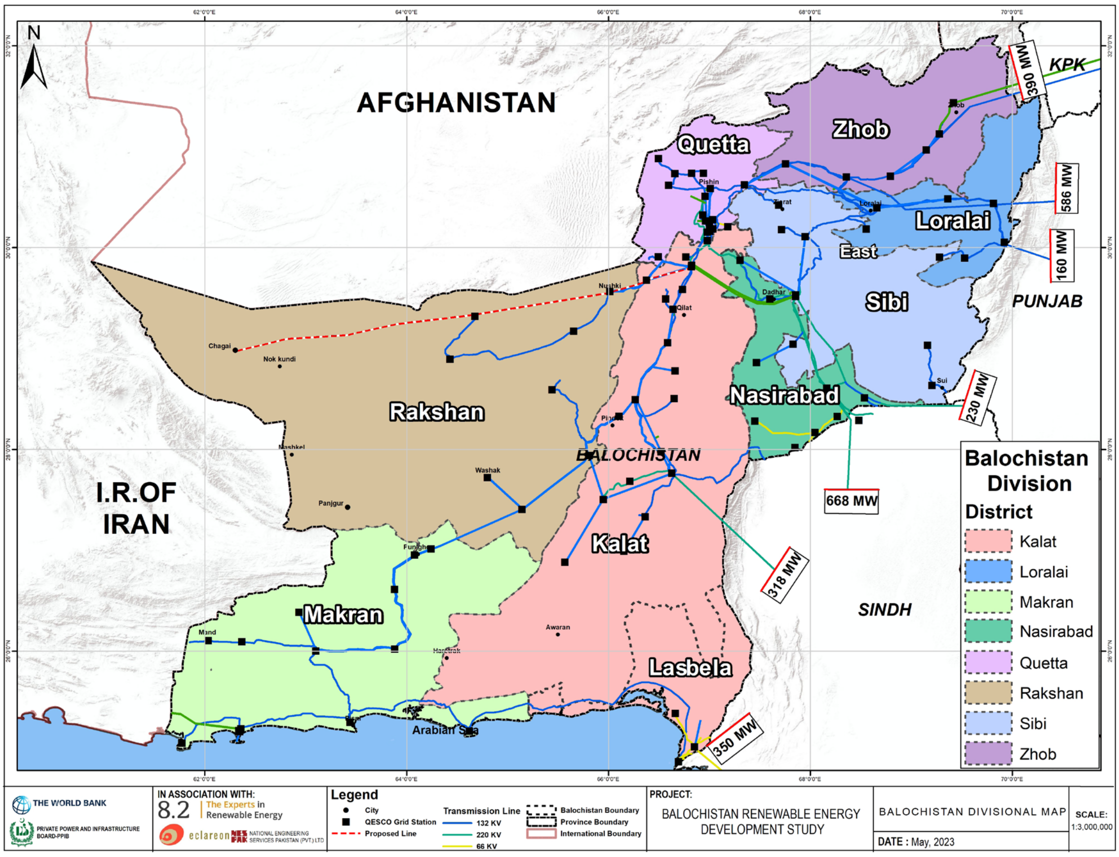
The table below summarizes the salient features of the identified sites. Land allocation has been completed for a few selected sites by the Balochistan government for existing developers through BECL.

Table 4.6: Identified VRE sites for existing grid

SN	Tec	Site	Loc Study DC	AEDB BED DC	NTDC DC	Optimal 1.3 x AC DC	Pakistan connection capacity	AC evaluated	Land status
1	PV	Musafirpur	50			50	DI Khan-Zhob 220kV (390 MW)	40	
2	PV	Zhob new				460		350	
3	CSP	Loralai CSP				100	DG Khan-Loralai 220kV (586 MW) Sarwar/ Rakhni 132kV (160 MW)	100	
4	PV	Muslim Bagh (Killa Saifullah)	132		150	130		100	
5	PV	Drazanda (Loralai)	132		150	130		100	
5	PV	Chinali (Loralai)	132			130		100	
6	PV	New Loralai 1				150		115	
7	PV	New Loralai 2				420		322	
8	PV	Khuzdar	244	50	300	260	Dadu-Khuzdar 220kV (318 MW)	200	
9	Hyb	Panjgur	254	50	75	260		200	
10	PV	Khuzdar New				420		320	
11	PV	Kuchlak (Quetta)	200	200	189	200	Guddu/ Shikarpur-Sib-bi-Quetta 220kV (898 MW)	153	Earmark
12	PV	Kuchlak (Quetta)		100		110		85	Earmark
13	PV	Kuchlak (Quetta)		50		50		42	Earmark
14	PV	Khanozai (Pishin)	120			110		85	
15	PV	Mastung	120			110		85	
16	PV	Bostan (Pishin)	120	100	40	110		85	
17	PV	Mangochar (Kalat)	120			110		85	
18	PV	Kalat	120			110		85	
19	PV	Harnai (Sibbi)	120			110		85	
20	PV	Mach (Kachi)	132		100	130		100	
21	CSP	Quetta (CSP)		100	40	127		127	
22	PV	Quetta New				350		267	
23	PV	Gwadar (220kV)		50		180	Iran-Gwadar 132kV (135 MW)	135	
24	PV	Winder (Lasbela)		50	50	50	350 MW to KE	42	
25	PV	Uthal (Lasbela)		50	25	50		43	
26	PV	Bela (Lasbela)		50	50	40		25	
27	PV	Hub	210	150		590		450	
		Total Capacity	2,206	1,000	1,169	5,047		3,926	

The analysis of the grid has identified an interconnection capacity of approximately 2.35 GW from Balochistan to other provinces of Pakistan, excluding the separate connection to KE. Through supply–demand analysis, it has been simulated that even in a low-demand scenario, a maximum of 1.78 GW of power flow from Balochistan to other provinces can be expected during the daytime from April to June. This projection assumes the absence of distributed generation within Balochistan.

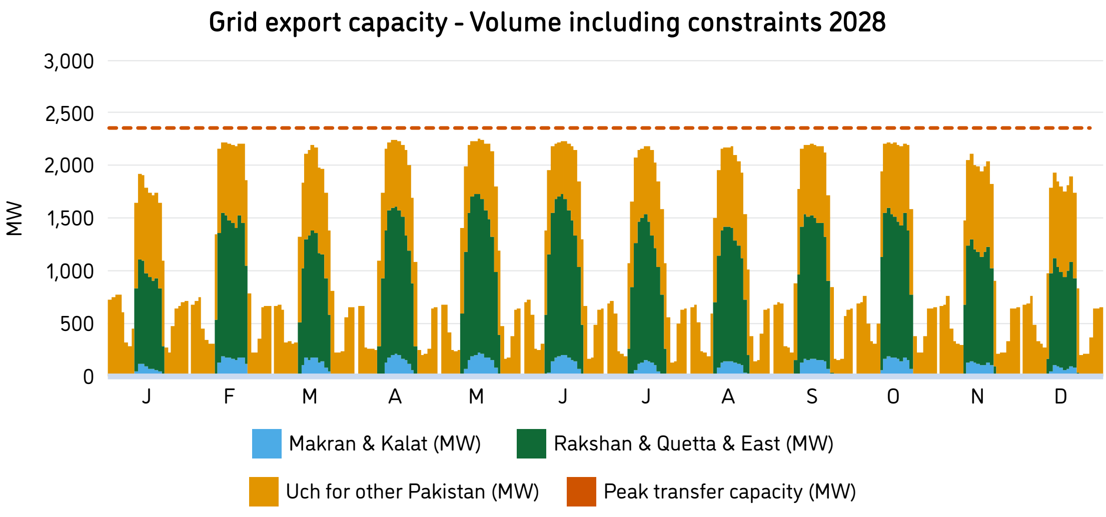
Figure 4.9: 2028 Export grid capacity based on transmission line lengths



To assess the feasibility, the operations of Uch I and II, which contribute to the same system, need to be considered. Uch I and II have a combined capacity of about 930 MW with an average capacity factor of 87 (NEPRA, 2022). For this analysis 930 x 0.87 = 809 MW has been considered. Additionally, it was assumed that VRE will be used for provincial demand; unmet demand (when VRE not exceeding the demand) will be partly met by Uch I and II, and remaining demand will be supplied from other provinces. If VRE exceeds the local demand, electricity will be exported to other regions of Pakistan. Uch I and II will also export until the 2.35 GW export line capacity of the QESCO grid is met, except for the Dadu-Khuzdar connection of 318 MW.

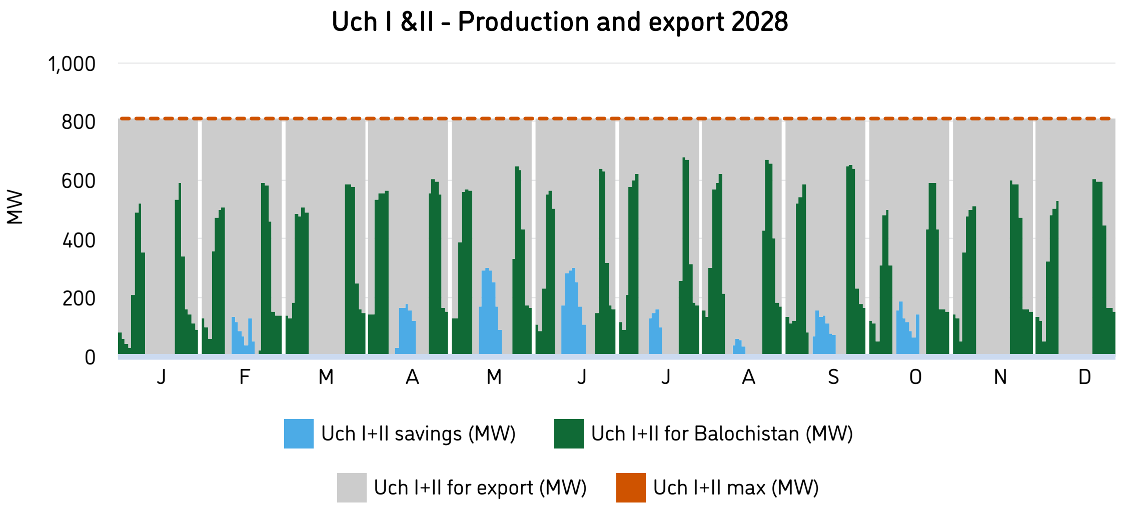
Even in the low-demand scenario of Balochistan, the cumulative capacity of interconnecting lines in QESCO grid will not be met so that line capacity does not need to be increased.

Figure 4.10: Total QESCO export volume over time at interconnection lines



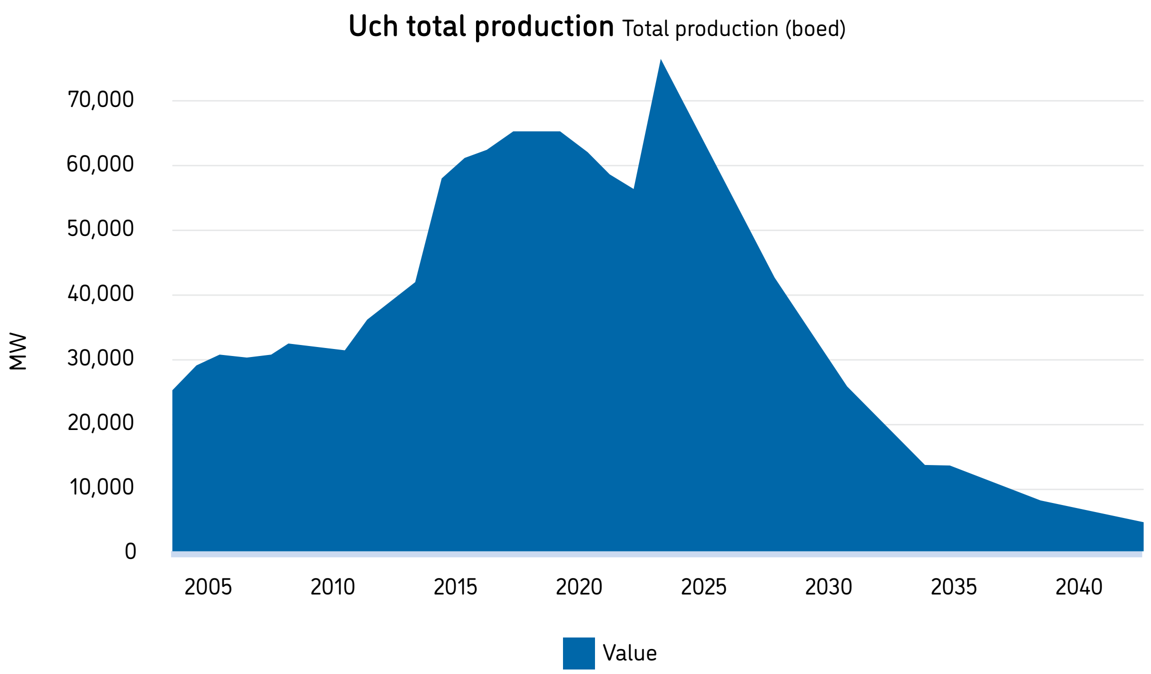
As shown in the figure below, there are certain months when the capacity of Uch I and II cannot be fully utilized due to limitations in their direct connecting lines and excess of VRE during that period. In a low-demand scenario, Uch I and II would curtail approximately six percent of their maximum annual output.

Figure 4.11: Uch I and II production simulation



For Uch I and II to be utilized fully either the lines could be debottlenecked or Uch I and II would need to reduce their output by six percent. Given that the gas field supplying Uch I and II is expected to reach its peak in 2025 (figure 4.12), this could prolong the lifetime of the gas field and extend the duration for which low-cost local gas can be utilized. This is particularly significant if, in the future, more VRE from Balochistan can contribute to additional savings. The value of gas as a balancing power source will be particularly high, especially after 2030, when the grid system will have greater VRE integration. The extended availability of local gas from Uch will help reduce dependence on costly imports during that period.

Figure 4.12: Uch I and II gas field lifetime projection



Source: Data Oil & Gas Intelligence Center

4.1.7 Security and Social Implications:

Local acceptance and community engagement are critical factors for the successful realization of RE projects. If RE projects are realized without the prior engagement of local communities, negative local perceptions can be expected. There are guidelines that include participatory processes that can lead to increased public acceptance. In any case, processes should be adapted to the local context of the Balochistan region.

General guidelines can be summarized in the following points (Lane & Hicks, 2017):

- Inform, that is, providing balanced and objective information;
- Consult, that is, elicit feedback from the community on the RE developer's decisions;
- Involve, that is, engage with the local community from the outset and in all stages of the development;
- Collaborate, that is, create a partnership with the local community, at all stages of the development, and work together to find alternative solutions whenever needed; and
- Empower, that is, support the local community to be a substantial part of or even lead project development.

One crucial point of the "Empower" dimension is that of shared benefits. In general, it should be ensured that the economic benefits generated by RE development are also shared locally, focusing on economic growth, job creation, and improved living standards. To enhance local acceptance and empower community engagement, three main categories of incentives are defined (Knauf, 2022):

- Discounted electricity tariff.
- Payments to the local government.
- Payments for social purposes.

Those three categories will overlap (they are not mutually exclusive).

Balochistan province has a comparatively higher security risk than other provinces in Pakistan. Foreigners need special permits to travel, and maintaining law and order can be a challenge. The implementation of infrastructure development projects can be facilitated through engagement with tribal leaders.

The security situation is also affected by poverty and lack of facilities in the region. The security situation generally can be improved through confidence-building measures, such as setting up education and health facilities.

For large RE developments, these risks can be mitigated considering the following:

Provided that a utility-scale RE system in the neighborhood is not installed on disputed land and does not affect the local population's day-to-day life, only positive effects can ensue, not least because the installation and O&M of the system has the potential to create both temporary and permanent jobs. It is recommended and assumed that the developer make an effort to offer unskilled jobs to the local population and train local people for permanent O&M and security jobs. Since the BECL is expected to be a partner in plant development and ownership it is the responsibility of BECL to look after this aspect.

This study assumes that US$1/kWp per year will be diverted toward local development. For a 100 MWp project this would be US$100,000, a significant yearly amount. It is envisaged that an elected group of local representatives and the operator will decide on and monitor the funds. The distribution of funds will be made conditional on uninterrupted plant operations. The community should feel a sense of ownership and also be aware of reprisal in case of non-cooperation. Some examples on participation are described in ANNEX B: Socioeconomic Impact.

4.2 Demand from Mining until 2028

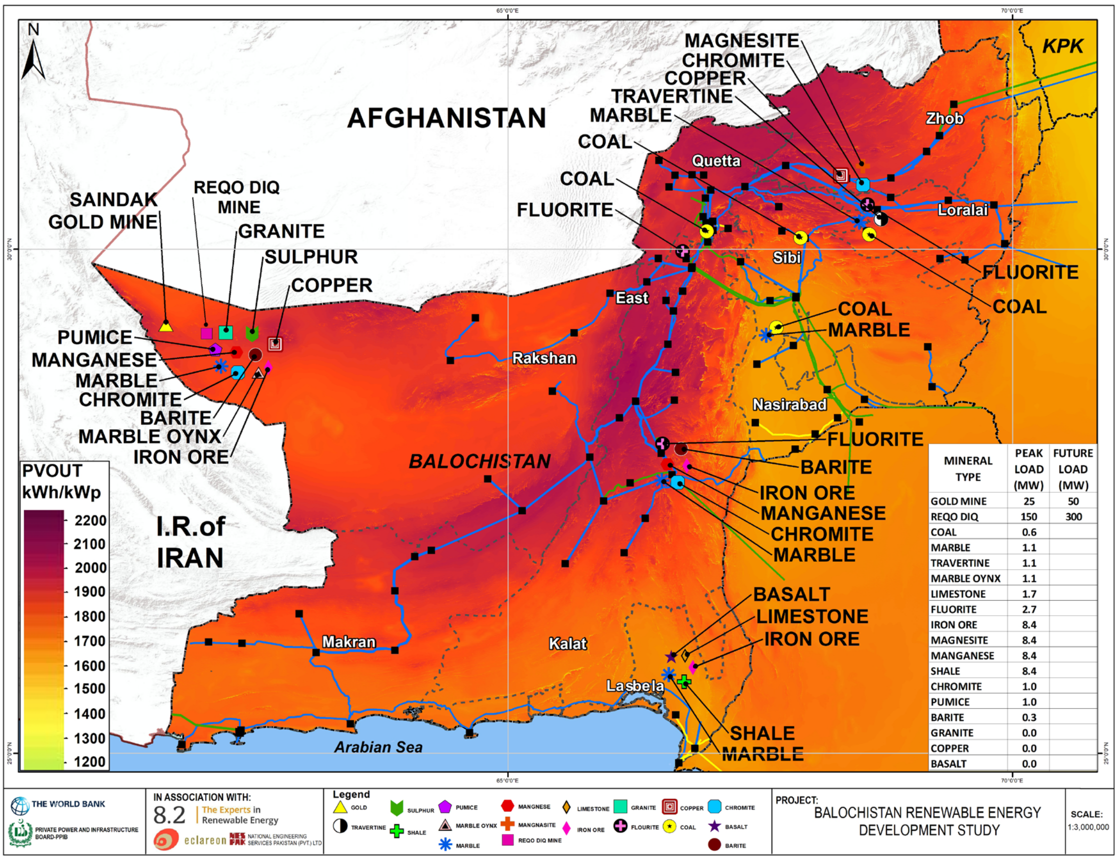
4.2.1 Identified Opportunities

The mining industry plays a significant role in the region's economy and development. Balochistan is known for its rich mineral deposits, such as copper, gold, chromite, coal, and natural gas. The province has attracted both national and international mining companies due to its resource potential. The mining industry in Balochistan has the potential to contribute substantially to the national economy and create employment opportunities.

However, the mining sector in Balochistan faces various challenges, including inadequate infrastructure, limited access to modern technology and expertise, and security concerns in certain areas. Additionally, there have been concerns regarding the equitable distribution of benefits from mining activities and the protection of the rights of local communities. Efforts are being made to address these challenges and promote sustainable mining practices in Balochistan. In collaboration with international companies (namely MCC and Barrick Gold) and private investors, the government of Pakistan is working toward improving infrastructure, promoting transparency in the sector, and ensuring the participation of local communities in decision-making processes.

The sustainability aspect of green power sourcing for mines is an important consideration. In this regard, Balochistan has the potential to provide both environmentally friendly and cost-effective electricity. As most mines are located in remote areas without access to the public grid, this power supply for mining sites is to be considered separately from the on-grid VRE potential discussed earlier.

Figure 4.13: Mining areas and PV resource



MINERAL TYPE	PEAK LOAD (MW)	FUTURE LOAD (MW)
GOLD MINE	25	50
REQO DIQ	150	300
COAL	0.6	
MARBLE	1.1	
TRAVERTINE	1.1	
MARBLE OYNX	1.1	
LIMESTONE	1.7	
FLUORITE	2.7	
IRON ORE	8.4	
MAGNESITE	8.4	
MANGANESE	8.4	
SHALE	8.4	
CHROMITE	1.0	
PUMICE	1.0	
BARITE	0.3	
GRANITE	0.0	
COPPER	0.0	
BASALT	0.0	

The Balochistani mining industry has the potential to contribute significantly to the economic development of the province and the country as a whole. With proper planning, investment, and stakeholder engagement, the province can harness its mineral wealth to create a sustainable and inclusive mining sector that benefits both the local communities and the national economy. Two such noteworthy mining sites, together with their options for VRE power, are described below.

The Saindak copper and gold (Cu-Au) deposit is a hydrothermally altered porphyry-type deposit with medium- to low-grade copper (Cu) and gold (Au), along with minor silver (Ag). Equipment used in the mining operation includes electric face shovels, trucks, support equipment such as dozers (bulldozers) and graders, and water trucks. The infrastructure requirements for this relatively large mining and processing operation include significant quantities of power, water, consumables, and manpower. Electricity is generated by heavy oil engines with a total capacity of 50 MW, supplying power to the mine, processing facilities, and the township. Water is sourced from underground wells located 37 km away and pumped to storage dams on site. Additionally, water is recovered from concentrate and tailings dewatering operations, including the tailings dam, for reuse in the process.

Most of the local mines have relatively low electricity requirements compared to international mines. The total electricity requirement is estimated to be 65 MW (excluding Reko Diq), of which most is supplied off-grid through locally available HFO or diesel. The mines are mostly located in remote areas with limited grid access. PV plants can be deployed at such sites for fuel savings during the daytime. Deployment of wind and CSP technology is also possible but constrained by resource availability. A combination of these technologies (PV, wind, and CSP) along with a battery energy storage system (BESS) can provide a complete off-grid RE solution with considerable cost savings in term of fuel.

To illustrate the potential for VRE to power these mining activities, two case studies have been prepared for two new mines in the planning phase where data on load could be obtained. Based on the results of the case studies and available data on the mining sector, results have been extrapolated for the mining industry. It is estimated that 250 MW of wind and 220 MWp of PV could be implemented by 2028.

4.2.2 Case Study 3 – Reko Diq Mine

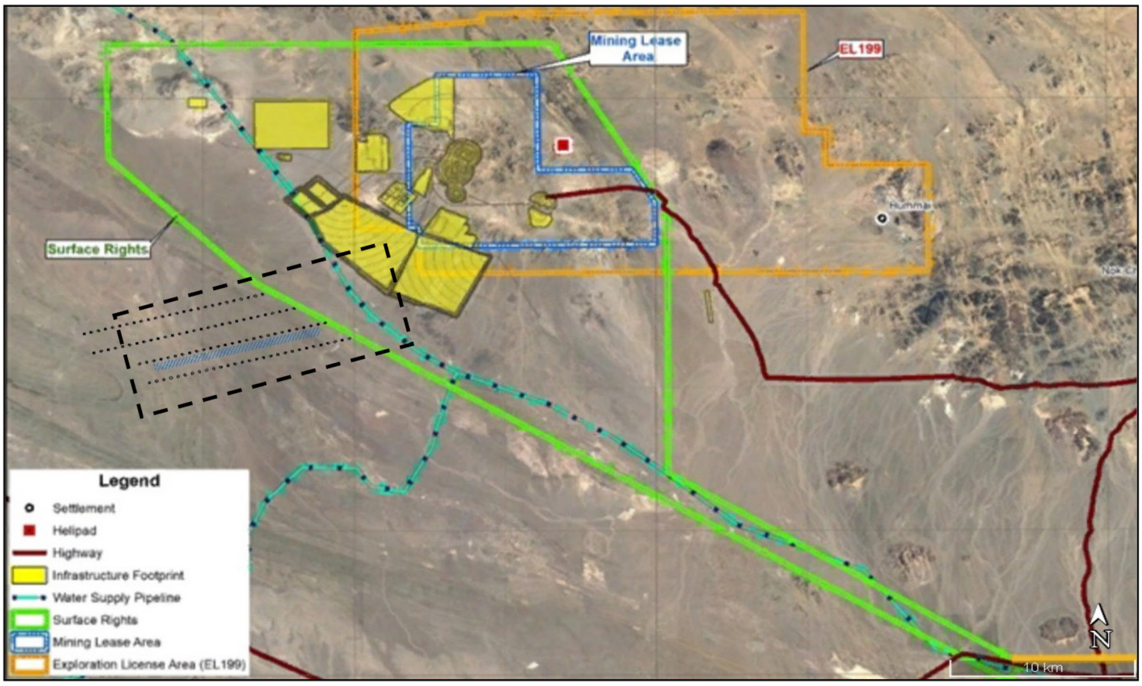
The Barrick Gold Corporation plans to develop the Reko Diq mining site in Chagai, Balochistan. The mining operation will produce 40 million metric tons per annum of copper plus the same yearly tonnage of gold ore in the first phase by 2028. Based on initial information obtained from the company (Barrick Gold, 2023), it is estimated that the peak electricity demand at the site for this phase will be approximately 150 MW annually. There is no operational grid in the area, so the electricity demand for Reko Diq would need to be met through a local plant. Based on currently available information, it is expected that HFO-based power plants will be installed for energy needs. The expected cost of electricity, including transportation charges, would be US$0.26/kWh approximately, with the emission of 1 kg of CO_2 per kWh, that is, a yearly economic cost of US$340 million, and an environmental impact of 1.3 million metric tons of CO2 per year.32 These are not trivial quantities.

Meanwhile, however, the area around the project site offers superb locations—by global standards— for both wind and PV power generation. Due to the excellent resource availability and generation pattern on site, these two sources could meet more than 85 percent of the annual electricity demand. The remaining 15 percent of the annual electricity demand will be met by an HFO plant, resulting in a total cost of US$0.12/kWh. The annual savings for the company would be approximately US$136 million per annum compared to the operation of an HFO plant.

A possible geographical layout of the hybrid RE plant is depicted in the figure below.

32 Own simulations, for details please refer to complete prefeasibility study.

Figure 4.14: Layout of proposed wind-PV plant (indicated by dashed rectangle)



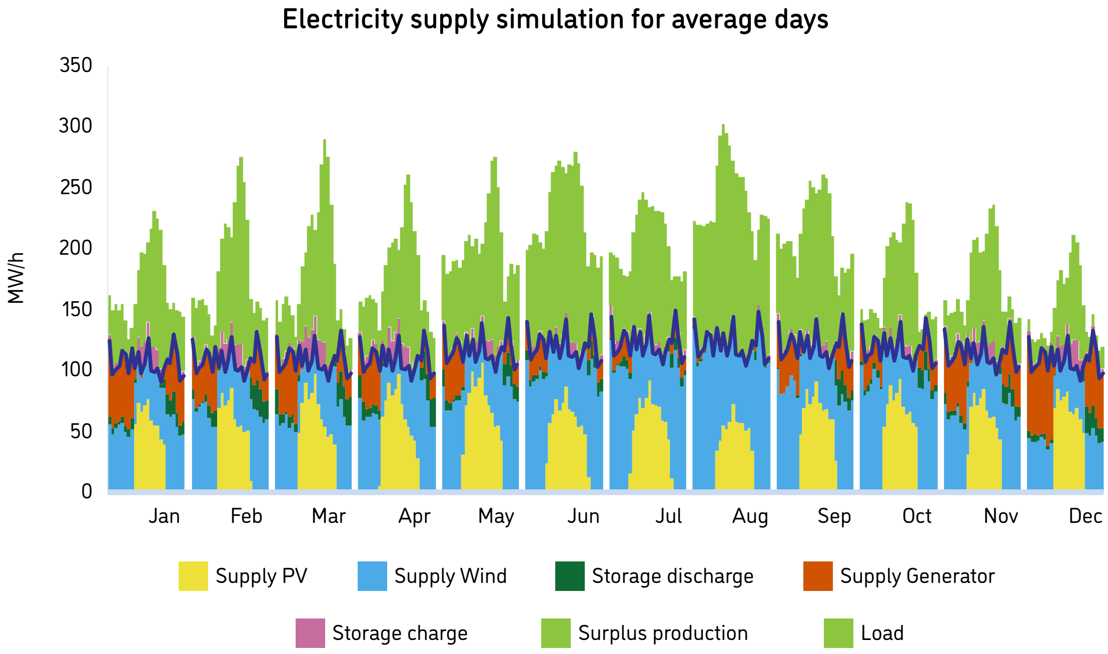
The first step in the design is the micro-siting of the wind turbines, as determined by prevailing wind direction and high wind resource in and around the Reko Diq site. Thereafter, the PV trackers are optimally placed in between wind turbines to reduce shading losses.

The optimized total supply cost including investment and fuel is estimated at around US$0.121/kWh by combining battery storage with 150 MW HFO backup power. The generators are essentially required for the purpose of backup and safety; therefore, only CAPEX needs to be considered. The elimination of GHG emissions would amount to 20 million metric tons of CO_2 over 25 years, and the annual savings result in an NPV of US$1.4 billion over 25 years at a discount rate of 12.5 percent.[33]

A third party would assume the role of an IPP and invest in this hybrid RE plant in order to sell the electricity to Barrick Gold as the bulk power consumer[34] so that Barrick Gold would not itself have to invest. This is standard business practice in Pakistan, in line with NEPRA rules, regulations, and guidelines. The same logic and economics apply to the second phase of the plant, which is also expected to serve a peak load of 150 MW.

33 GHG reductions have not been financially evaluated.
34 Bulk power consumer as defined in the NEPRA Act: Regulation of Generation, Transmission, and Distribution of Electric Power Act, 1997.

Figure 4.15: Annual production profile of RE sources at Reko Diq site



To meet the energy demand of the mining operations, the lowest-cost RE hybrid plant, comprising 200 MW solar power and 250 MW of wind power, would produce approximately 40 percent of excess energy that will be wasted.[35] However, if the project site is connected to the national grid at some point in the future, the surplus energy could be exported to the national grid and any deficit energy imported. In this case, battery storage would no longer be needed, and the HFO plant would only be used for emergency operations—further reducing the cost of electricity with a highly attractive expected payback period of 4.4 years.[36]

Barrick Gold has initiated a feasibility study for the mining project. Furthermore, a detailed feasibility study of the power project should be commenced soon. Barrick Gold's indicative timeline suggests production in 2028.[37] Based on the current Pakistani power sector situation, it is assumed that a commercial operation date could be achieved by 2028 with a considerable margin.

The following table summarizes the economic output of the simulation of different energy supply cases to understand the lowest-cost solution for Reko Diq. The simulation shows a grid connection to Mastung over 500 km that has the lowest overall cost of US$ 8.9 cents/kWh if combined with a local hybrid system of 200MWp PV and 250MW wind (case 6). The otherwise curtailed excess electricity production can be evacuated by the new line. [38]

35 The marginal unit of installed PV and wind energy will cost only US$0.2/kWh at 80 percent curtailment as the marginal production cost is only US$0.04/kWh.

36 Presumably the grid connection was not planned up to 2022 as the agreement for development was reached in 2023.

37 Barick Website. Operations, *Reko Diq*

37 Consultant report on Detailed Analysis of Hybrid RE Opportunity at Reko Diq Mining Site provides more details.

37 All alternative cases also include an HFO plant as a backup.

Table 4.7: Case summary and economic results

Economic Output	Case 1 HFO Base case[39]	Case 2 Off-grid PV	Case 3 Off-grid PV + Storage	Case 4 Hybrid + Storage	Case 5 Grid PV	Case 6 Grid + Hybrid
PV MWp	0	150	350	200	150	200
Wind MW	0	0	0	250	0	250
Battery MWh	0	0	350	250	0	0
Production surplus %	0%	0%	28%	40%	0%	44%
HFO fuel / Grid supply (US$, millions/year)	257	168	107	38	98	-2
RE load utilization %	0.0%	35%	59%	85%	35%	81%
Total CAPEX (US$, millions)	0	96	313	501	230	560
OPEX (US$, millions/year)	257	170	116	49	103	8
CAPEX Grid (US$, millions/year)		6.5	6.5	6.5	140	140
PPA incl. grid cts/kWh	25.6	18.3	16.1	12.1	13.5	8.9
GHG reduction Mt CO_2	0.0	8.2	13.9	20.3	8.2	34.1
NPV company (US$, millions)	0	689	963	1,385	1,163	1,695
Initial year savings (US$, millions)	0	73	96	136	121	168

4.3 Impact of distributed PV

4.3.1 Situation and Obstacles

Distributed generation from PV (DPV) is not the main focus of this study. However, based on the feasibility study done by NTDC (2022) it presents a significant opportunity at the provincial level. Depending on its scale, the implementation of DPV can significantly change overall grid capacity, in fact, this could become a constraint for the grid-connected utility plants, in that the free grid capacity will be taken over by DPV. The main opportunities associated with DPV are net metering and solarization of agriculture tube wells. However, the net metering potential is more of an urban and industrial application, of little significance in Balochistan except for Quetta. This study assumes the impact of net metering to be integrated in the demand forecast.

In Balochistan, there are approximately 29,500 grid-connected agriculture tube wells, which consume 70 percent of the current electricity supply. The electricity for these tube wells is highly subsidized[40] and payment collection is a challenge, resulting in significant losses for QESCO and thus for Pakistan. This subject is of prime importance to Pakistan as insufficient payment recoveries are adding to the burgeoning circular debt (more than US$340 million 2022/23 and growing). Additionally, the unsustainable use of groundwater for irrigation is depleting the water table quicker than it can be replenished.

4.3.2 Solution proposal

In 2021, the NTDC commissioned a feasibility study to address the circular debt problem and unsustainable water usage. The study (NESPAK, 8p2, 2020) was delivered in 2020 and is based on a quantitative analysis using QESCO data, stakeholder information, site visits and measurements at over 250 farms across Balochistan. The study discussed the following solutions and observations:

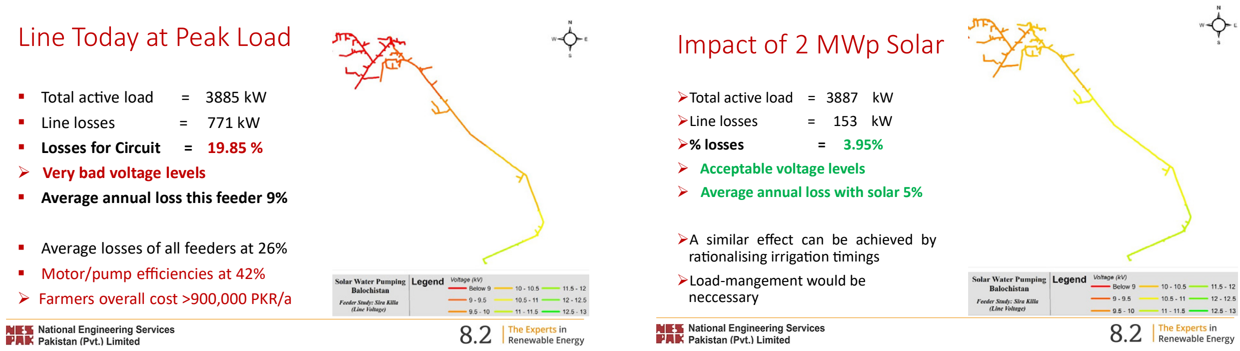
40 Farmers pay a fixed amount of 10,000 PKR/month for 5,400 kWh.

Electricity Supply

- Due to nonpayment by farmers, QESCO restricts the electricity supply to 4–6 hours per day on whole feeders;
- Power supply is insufficient for irrigation needs in the peak season and voltages are too low;
- Inefficient motors and pumps are in use, and due to low voltages farmers repair motors annually;
- Farmers install additional motors and pumps to use power in shorter time windows;
- Resulting voltage is even lower and detrimental for motors and pumps—resulting in very high line losses; and
- About 50 percent of today's wasted energy supply could be recovered with new motors and pumps, PV electricity for local supply, and optimized load-shedding schedules.

The following figure illustrates line operation during peak load, along with a list of issues and their current status updates. The actual hourly load and supply data from 2018 were retrieved from QESCO, and the loss and voltage simulation of the line were performed in OpenDSS.

Figure 4.16: Loss and voltage simulation of Sira Qila feeder with and without DPV



Source: (NESPAK, 8p2, 2020)

Payments

- There is no proper metering/billing system for the electricity consumed by the local community both for the sanctioned and additional transformers. Moreover, the farmers do not feel any obligation to pay for a clearly insufficient electricity supply that experiences heavy load shedding;
- Farmers face additional expenses for procuring diesel to keep their motors running during the peak season, as well as incurring costs for the repair and maintenance of these motors; and
- Farmers could be motivated to pay for a reliable supply of high-quality electricity.

Water Nexus

- Irrigation practices can be improved to reduce water consumption by about 10 percent;
- Water is wasted during the off-season as farmers do not save electricity even when water is not required; and
- The water table is depleting at an average rate of 4 m/annum, which could be addressed by improved practices and paying for the electricity consumed.

The following interventions have been proposed in the feasibility study:

- Augment the feeder lines with PV electricity to stabilize and maintain line voltages;
- Off-grid solutions such as a stand-alone solar system are not recommended, being twice as costly and having a high risk of extracting more water than needed and wastage of energy during the off-season. Extracting more water would increase the problem of the already decreasing groundwater table which can be observed in many parts of Balochistan;

- Load shedding patterns should be adjusted to minimize line losses;
- Farmers should be supplied with efficient motors and pumps that can be controlled remotely to deliver sufficient water to meet crop requirements;
- Farmers can be encouraged to save electricity and hence reduce water consumption by selling saved electricity through net metering;
- The circular debt of US$340 million/year can be eliminated by a subsidy scheme of around US$20 million/year for implementing DPV. This subsidy would be available to farmers for the first 15 years, after which the farmers will be in a position to pay for their consumption as do other customers; and
- It was proposed to pilot the concept on one or two typical feeders before it is rolled out at a larger scale.

Status since the Feasibility Submission

The government of Balochistan decided to opt for an off-grid PV supply to farmers, coupled with the removal of electricity lines. That solution was ruled out in the feasibility study as too expensive,[41] socially unacceptable, and too risky for the water table development as the farmers would have no checks and balances and virtually free electricity during the off-season. The PC1[42] was deferred by the planning commission for these reasons.

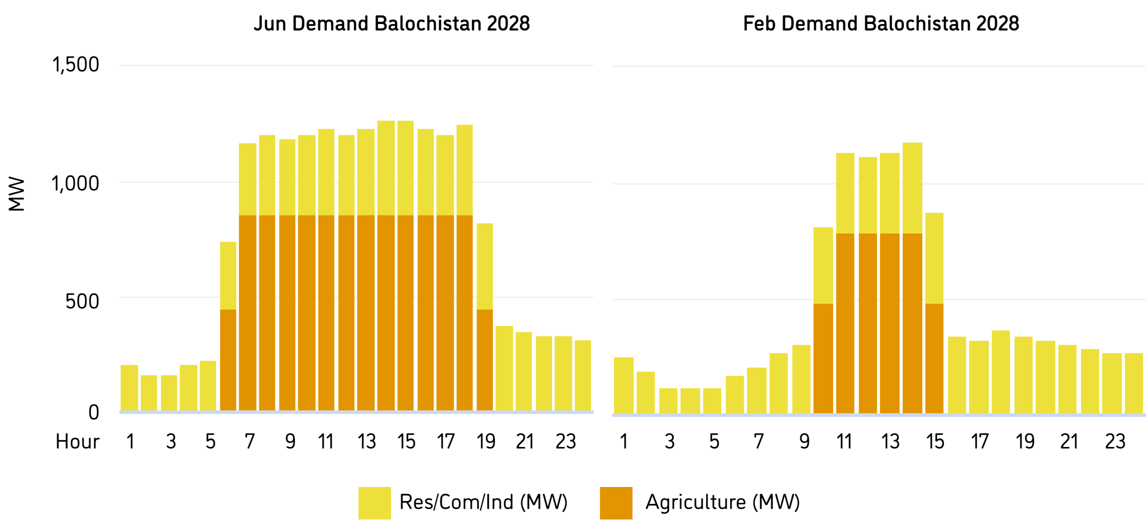
In spring 2022, the Secretary of Power, the MoE Power Division, agreed to initiate a pilot program for the proposed solution outlined in the feasibility study. The World Bank expressed its willingness to provide financial support for such pilot projects. In November 2023 MoE Power Division requested the World Bank to fund a pilot feeder to prove the concept.

A maximum of 2.4 GWp of DPV could be added in the province at 11 kV feeder level if the government of Balochistan implements a solution for all feeders in question.

4.3.3 Potential Renewable Energy Supply

The electricity demand for agriculture tube wells is well-researched. The following figures show 2.4 GWp DPV installation at 11 kV feeders to supply electricity to the tube wells. During the summer season, there is an energy deficit that would be fed by the grid, whereas during the winter season excess PV energy will feed back into the grid.

Figure 4.17: DPV supply and agriculture tube well demand in two example months



41 Off-grid supply requires a sizing for peak electric needs which is 100 percent more than in a grid-connected scenario.
42 Government of Pakistan, Planning Commission, proforma for development projects.

4.3.4 Grid situation and Debottlenecking

Most of the 11 kV feeders in Balochistan have the potential to absorb small-to-medium scale PV plants. The specific size and locations would need to be assessed individually.

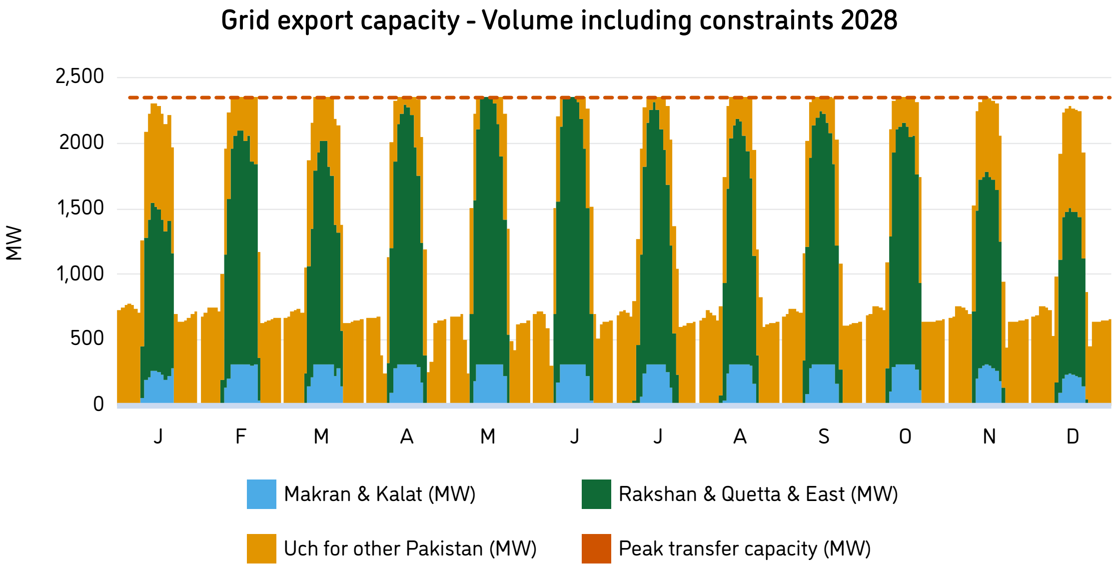
However, the distributed generation with PV (DPV) supply reduces the gross load of Balochistan by approximately 50 percent with a 75 percent penetration rate of DPV, which translates into 1.3 GWp of installed DPV.

I. The system losses imposed by the present supply pattern, inefficient equipment, and over-pumping will be reduced significantly, leading to the overall reduction in the demand for electricity by around 25 percent.

II. The supply of DPV energy reduces the gross demand for electricity by another 25 percent.

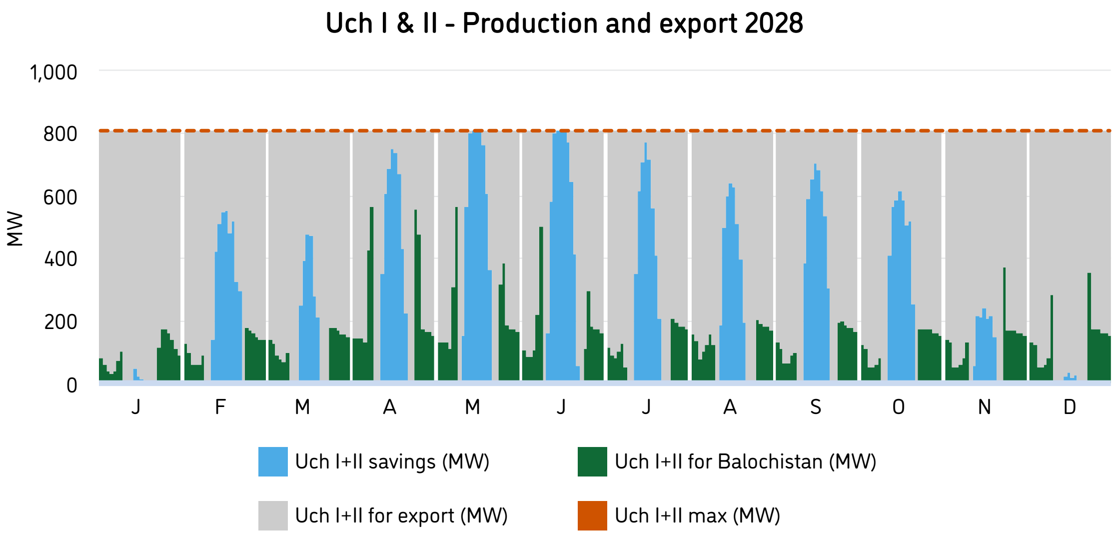
Both factors have been modeled and tested with the 2028 grid model of the NTDC. The additional DPV electricity and gross demand reduction are still within the export capacity limits. However, the output of Uch I and II would be limited due to interconnection line capacity constraints at an 80 percent safety level.

Figure 4.18: Balochistan–Pakistan interconnection volume – low demand – 1.3 GWp DPV



In the case of 1.3 GWp installed capacity of DPV by 2028, the fuel savings of Uch I and II would increase to 17–22 percent for the expected and low-demand scenario.

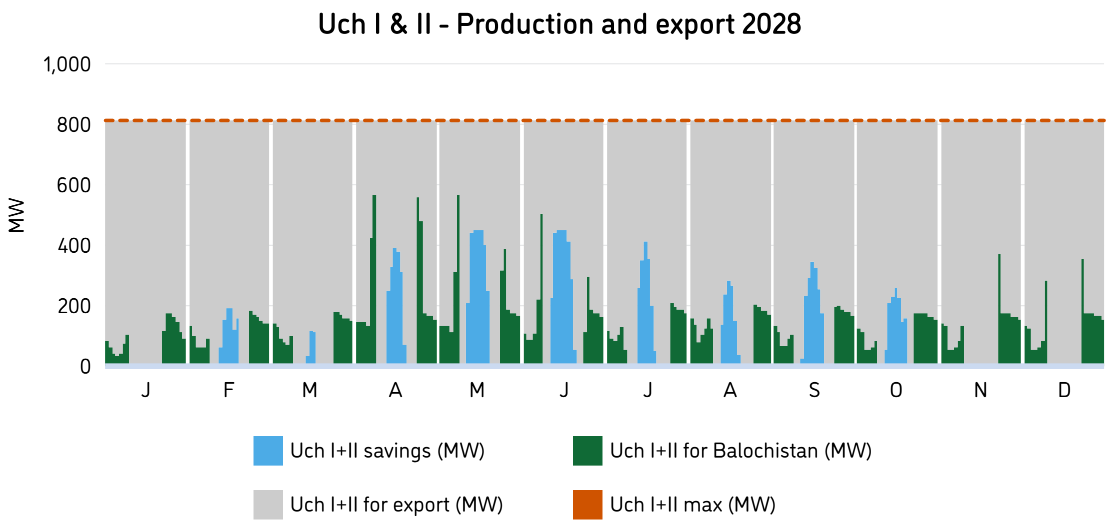
Figure 4.19: Uch–Pakistan interconnection volume – 1.3 GWp DPV impact on Uch I&II



The evacuation capacity-related savings would extend the lifespan of the Uch plants by one-fifth of the baseline projected lifetime.

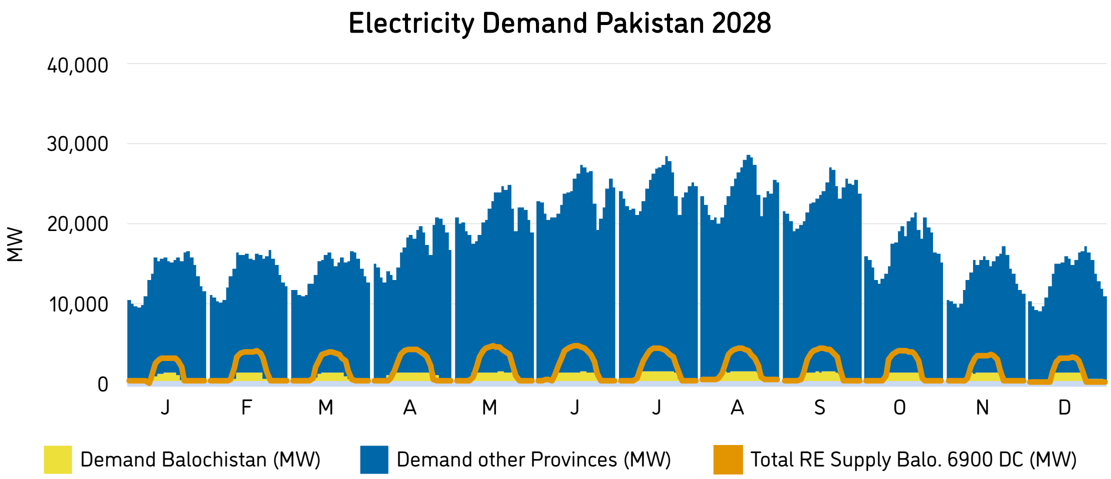
Alternatively, the transmission line capacity constraint of 80 percent might be expanded for a few hours a day in summer to allow for more peak exports if the supply situation in the country is severe. However, in this scenario, despite the presence of 1.3 GWp of DPV, the annual savings of Uch would be reduced to six percent.

Figure 4.20: Uch–Pakistan interconnection volume – 1.3 GWp DPV – 100% transmission capacity



In a broader perspective, Balochistan would contribute a greater amount of VRE electricity to Pakistan with the inclusion of DPV systems.

Figure 4.21: Pakistan supply–demand balance 2028 including DPV



5. Longer-Term Opportunities until 2033

5.1 Gigawatt Hybrid Park

5.1.1 Current situation

A near-term implementation plan (until 2028) has been discussed and analyzed in this report. However, more reliable least-cost energy options are available in the long run that will require additional installation of hydro, solar PV, and wind power plants.

Although the IGCEP 2022 shortlisted 11.92 GW of utility-scale RE parks throughout Pakistan, further studies indicate that the optimal approach is the installation of GW-scale RE parks at twice that capacity (8.2, PPI, 2023).

While hydroelectric power generation can offer low-cost electricity, there are several factors that contribute to the protracted and uncertain development cycle and accentuate the inherently capital-intensive nature of these projects. The long development cycle, capital-intensiveness of the technology, high hydrological risk, and low power-supply security are a few of the challenges faced by these projects. To mitigate these challenges, careful planning, risk assessment, and accounting for environmental considerations are essential.

As wind resources are much more scattered than solar, opportunities for GW parks are bound to be located in high-wind areas such as Jhimpir (Sindh), Chagai, and Panjgur.

The Chagai region in western Balochistan, close to the Reko Diq mining site, possesses significant potential for wind and solar PV electricity co-generation. The abundance of resources, such as high wind speeds and ample sunlight, makes it an attractive location for RE development. This area's vast available space further enhances its potential for generating green energy at low costs. In the vicinity of Panjgur, a similar opportunity exists. There is flat and barren land with excellent wind and solar resources.

Figure 5.1: Locations of proposed GW parks – dominated by wind

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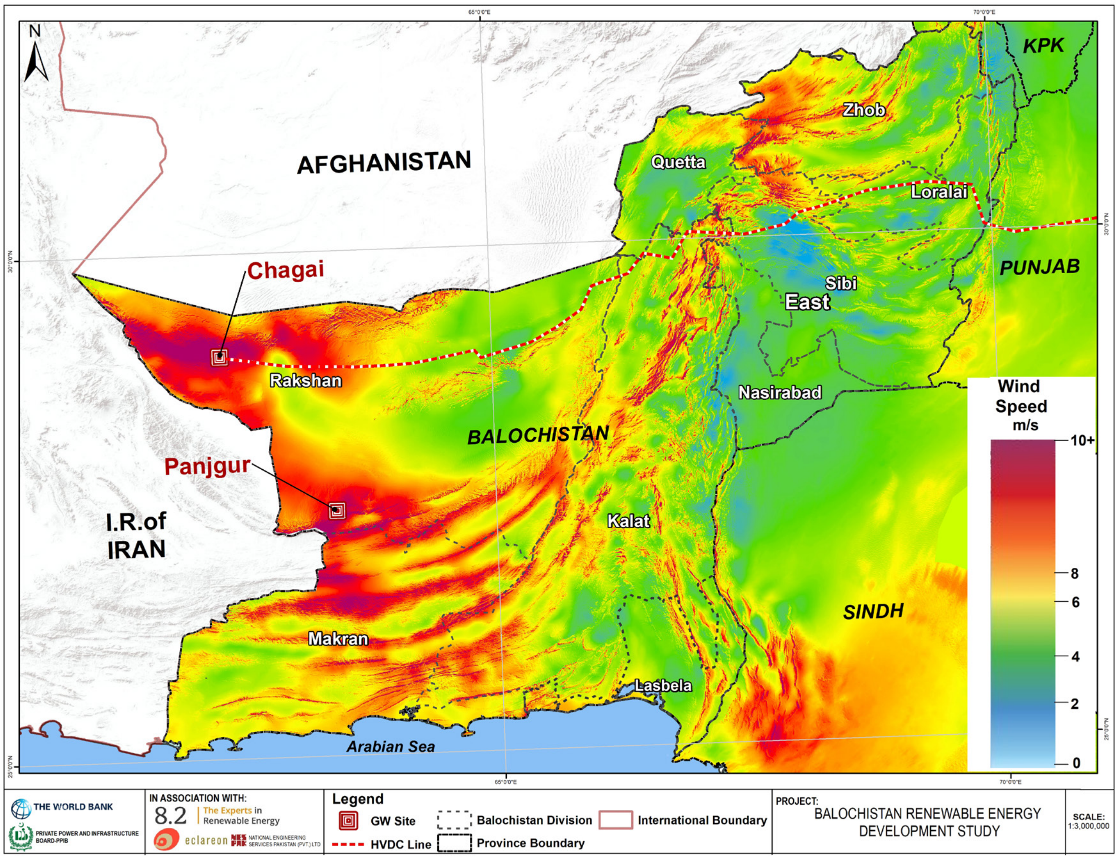


Source: Global Wind Atlas

On completion of the entire project, including scaling up to 7–9 GW, it is not expected to cost more than US$0.065/kWh, including the cost of evacuation of US$0.015/kWh. The excellent resources available in the Chagai region, including high wind speeds and ample sunlight, contribute to the high load factor achieved by RE projects in the area. A load factor of over 60 percent indicates efficient utilization of the installed capacity and a high percentage of time during which the power plant operates at its maximum output.

Comparing the load factor of RE projects in the Chagai or Panjgur region with typical hydropower plants in Pakistan, which have an average load factor of 55 percent, suggests that the RE projects in Chagai and Panjgur have the potential for even higher operational efficiency.

However, one key challenge that needs to be addressed is the requirement for an HVDC transmission line to evacuate the electricity generated in these remote areas and deliver it to the rest of Pakistan's grid. The costs of such a line and converter stations are very high and constitute up to 25 percent of the overall cost. With the possibility of scaling the converter stations gradually, it is feasible to achieve less than US$0.08/kWh PPA for electricity, even with less than 2 GW installed capacity. This benchmark aligns with the longer-term opportunities presented by GW-scale HPP projects.[43]

5.1.2 Case Study 4 – Chagai GW Hybrid Park

A large area in the Chagai region in western Balochistan, close to the Reko Diq mining site, is globally one of the best sites for wind and solar PV electricity co-generation. It has immense resources and space available and could generate green energy at very low costs; the only challenge remaining is the requirement for an HVDC line to evacuate the electricity from this remote region to the rest of Pakistan.

Within the Locational VRE Study (World Bank, 2021), this site was identified as ideal for a GW-scale solar-wind hybrid park and analyzed on a high level; this section lays out how such a plant could possibly look in more detail. A GW park in Chagai could start with 2 GW of wind and solar and be scaled up to 3 GW of wind and even 6 GWp of PV, all being evacuated with a 4 GW HVDC line from Chagai to Muzaffargarh.

In the first phase with only 2 GW installed, the cost of electricity would stay around US$0.08/kWh, which is the assumed cost of a new hydropower project including the necessary grid connection at the present cost of financing.

The cost-optimal configuration for the envisaged size would be 3 GW of wind and 4 GWp of PV power with a 4 GW HVDC line (± 800 kV). Depending on the next best alternative source of electricity, the DC capacity could be extended to about 9 GW.

When the envisaged full 7–9 GW is built, the expected PPA for the plant falls to about US$ 0.0646–0.066/kWh, including the cost of evacuation of US$0.015/kWh. This is possible due to the excellent resources at the site, combined with only small specific costs for transmission, as the connection line achieves a load factor of over 60 percent. Please refer to Figure 5.2 for

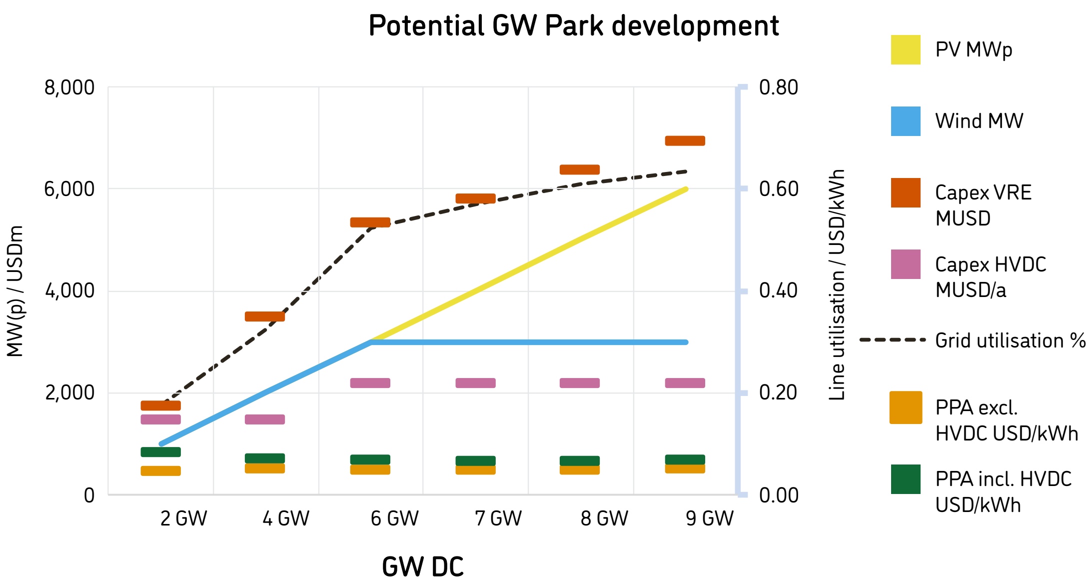
43 This assumes a weighted average cost of capital of 12 percent, CAPEX of US$2,300/kW, 300 km of 220 KVA grid connection, and a capacity factor of 55 percent.

Figure 5.2: Key data for further detail.

The alternative to such a GW park development is to construct a hydropower project of similar size. However, available data suggests that such hydropower projects come with a cost of around US$0.08/kWh and typically have an average grid load factor of 55 percent due to seasonal water availability. In comparison, a GW park in Balochistan offers greater financial attractiveness. Furthermore, implementing a PV–wind hybrid system would help mitigate the country's high risk associated with water availability in late spring and early summer, when electricity demand is very high, which is a concern for hydropower projects operated next to the Indus River.

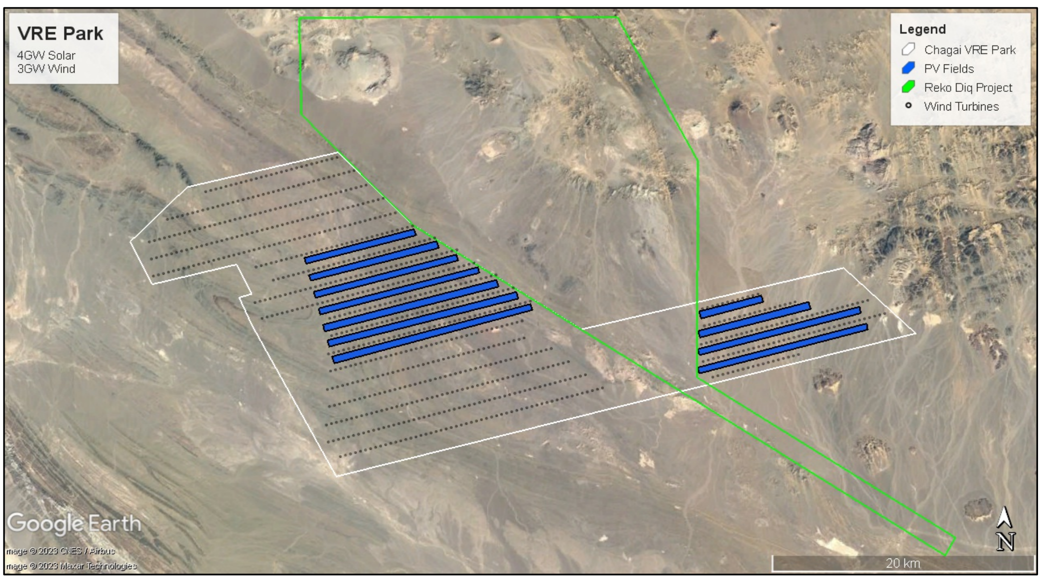
Finally, a VRE park can be scaled up over time including the possibility of scaling up the costly HVDC converter stations. As a result, the time required to bring the project to market would be considerably lower compared to the development of an HPP GW project. The graph below shows the key output indicators.

Figure 5.2: Key data for future large-scale RE power plants



The layout of the hybrid RE plant is depicted in the figure below.

Figure 5.3: Layout of proposed hybrid RE park



The project site is enclosed in a white boundary adjacent to the Reko Diq mining project (which is marked by the green boundary). Wind turbines are marked as black dots and PV areas as blue rectangles. The location was chosen because it is likely to have a hybrid plant comprising PV and wind technologies. This plant can be easily expanded, enabling initial evacuation through a 220 kVA connection to Mastung in the first phase.

This rough layout is a result of prioritizing wind turbine micro siting first, based on prevailing wind direction and high wind resources in and around the area. The micro siting would be evaluated closely at the feasibility stage, with attention to surface-specific detail. The area demarcated for Reko Diq mining projects has been excluded, as has any terrain presenting obvious challenges. After locating the wind turbines, PV trackers have been optimally placed between the wind turbines to avoid shading losses, running parallel to wind turbine rows. Although this orientation deviates slightly from the ideal orientation for a stand-alone ground-mounted PV system, the impact on solar resource loss is minimal due to the east-west tracking.

The full park would be split into smaller units of solar and wind plants, each of which could be built by a different investor. It is assumed that private investors would step in to invest in these solar and wind plants, acting as IPPs and selling the electricity to the CPPA. Under the prevailing RE policy, NEPRA rules, regulations, and guidelines, this is the standard business practice in the Pakistani electricity sector.

The table below indicates the water consumption for developing a hybrid park in Chagai, Balochistan.[44]

Table 5.1: Indicative water consumption in m^3 per day for 100 MW(p)

	Construction phase[45]		Operations phase	
	Freshwater	Drinking water	Freshwater	Drinking water
Wind project	80	16	2	0.04
Solar project	60	12	20	0.04

Since the Chagai site is devoid of any natural source of surface water, the main options below will be detailed during the feasibility phase:

1. Underground water wells (might be unsustainable).
2. Water bowser trucks ordered from other regions.
3. Desalination plants may be installed near the coast of Balochistan (very expensive).

44 Basis: Construction activities of a 100 MW wind project using 28–30 wind turbine generators (WTGs) and activities of a 100 MW solar project having approximately 180,000 PV modules have been assumed. Solar projects are assumed to have two cleaning cycles per month, each panel requiring 1–2 liters per cycle. The construction phase of a wind project may require 200–500 people over 18–19 months. The number of people on site may increase or decrease as the project progresses from early stages of construction to commissioning. The construction phase of a solar project may require 200–400 people over 10 months.
45 Subterraneous and geological conditions are unknown at this point, and water consumption could vary based on detailed geotechnical investigations.

Economic summary

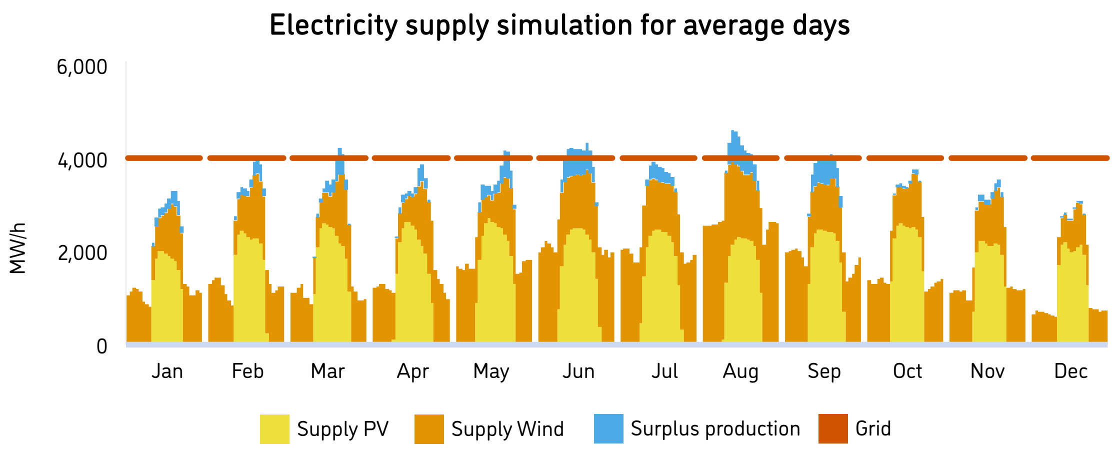
Table 5.2 summarizes key economic data including the NPV for the CPPA, comparing the hydropower park with VRE GW park in different development phases (supplying electricity at US$0.08/kWh at Chagai).

Table 5.2: Case summary and economic results and expected NPV at 12.5% DCF

Economic output	2 GW	4 GW	6 GW	7 GW	8 GW	9 GW
PV MWp	1,000	2,000	3,000	4,000	5,000	6,000
Wind MW	1,000	2,000	3,000	3,000	3,000	3,000
Production surplus %	0%	9%	2%	5%	8%	13%
Initial year RE GWh/a	6,089	10,983	17,786	19,374	20,656	21,506
Grid utilization %	18%	32%	52%	57%	61%	64%
Total CAPEX (US$, millions)	3,220	4,964	7,506	7,965	8,529	9,094
OPEX (US$, millions/year)	2,354	1,988	1,483	1,357	1,262	1,202
CAPEX HVDC (US$, millions)	1,475	1,475	2,168	2,168	2,168	2,168
RE PPA + HVDC cts/kWh	8.24	7.10	6.66	6.46	6.50	6.66
NPV vs. HPP CPPA (US$, millions)	915	2,504	4,566	5,266	5,568	5,550

The lowest average cost is expected to be 7 GW. Due to the low marginal cost of adding more PV, a total park size of 9 GW has the same expected average PPA as that of 6 GW park; however, the evacuation capacity factor increases from 52 percent to 64 percent. As wind turbines need more space to avoid wake effects and curtail fatigue stresses, wind deployment (in the highest wind resource region) is ultimately limited due to spatial considerations.

Figure 5.4: Hourly supply simulation during the year for the 7 GW case



An indicative timeline of the full hybrid RE GW park and its typical project development deliverables are depicted below.

Table 5.3: Indicative timeline for the hybrid RE project development at Chagai, Balochistan, Pakistan[46]

Activity / Milestones	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Technical feasibility studies	•	•	•							
Environmental studies		•	•							
Transmission line feasibility		•	•							
Grid studies		•	•	•						
Grid study approvals[47]			•	•	•					
EPC contractor bidding and negotiations			•	•	•	•	•			
Project auctions[48]				I	II	III	IV			
EPA and IA negotiations[49]				I	II	III	IV			
Signing of EPAs and IAs				I	II	III	IV			
Financial close					I	II	III	IV		
Transmission line construction							•	•	•	
Construction of projects						•	•	•	•	•
Start of operations									•	•

It is expected that hybrid park would consist of many smaller projects. These projects would be auctioned (based on reverse bidding) periodically over the next decade. Hence, separate tariff timelines have not been indicated, (usual in unsolicited projects). The agreed tariff would ultimately be announced by NEPRA after reviewing the project bidding documents, followed by conclusion of project security documents between the government of Pakistan and the successful bidder.

The full case study for the Chagai location is provided in Consultans Report: Detailed Analysis of GW Park.

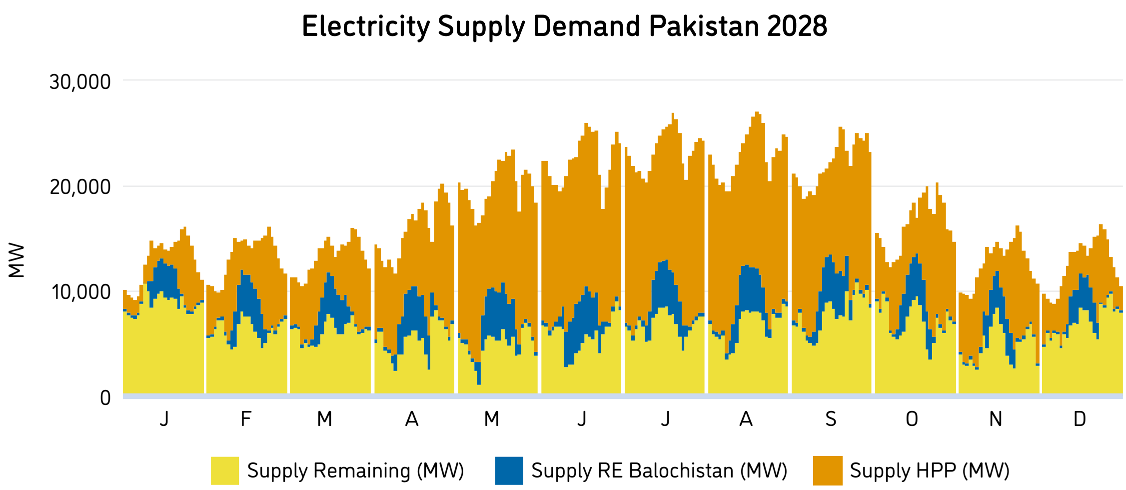
46 The timeline for developing the power projects may still change due to unforeseeable circumstances.
47 If the hybrid park is being auctioned by the government, the grid studies are originally expected to be conducted by the NTDC, in which case approvals may not be prolonged. Prior to the construction phase the grid studies may simply be reconducted by the NTDC with bidder-specific WTG, PV panel, and inverter specifications as per grid code requirements.
48 Based on current information, at least four bidding cycles are assumed.
49 EPA structure would depend on prevailing market regime and standards.

5.1.3 Potential Demand and RE Supply

The overall demand for additional electricity, beyond the existing grid, was established in Chapter 3 (Electricity demand and grid analysis). Once the other available locations (HPP or VRE) and the cost estimates and timelines involved are finalized, a hybrid GW park in Balochistan is expected to emerge as the most economically feasible option.

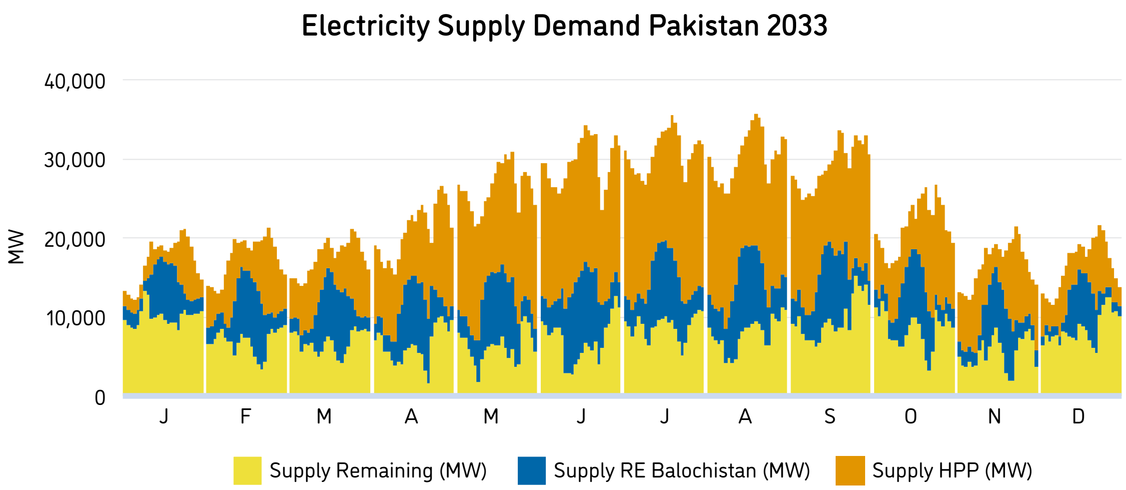
Large-scale RE projects must be integrated in a way that ensures grid stability and reliability considering the already identified utility-scale plants and low-demand forecast for Pakistan. Sufficient grid inertia and dispatchable supply should be in place when considering the addition of a significant 4 GW supply to the grid by 2028.

Figure 5.5: Balochistan RE supply including GW park in 2028 low-demand forecast



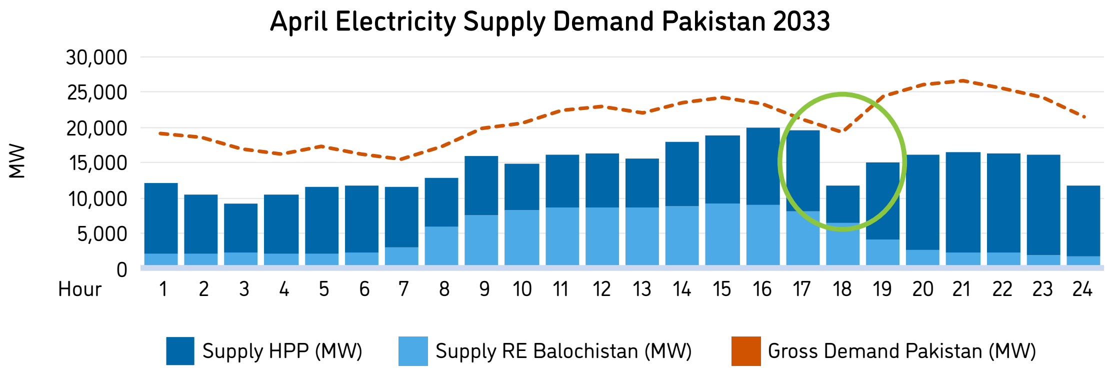
However, in the 2033 scenario, the GW park at full output looks feasible even in a low-demand scenario.

Figure 5.6: Balochistan RE supply including GW park in 2033 low-demand forecast



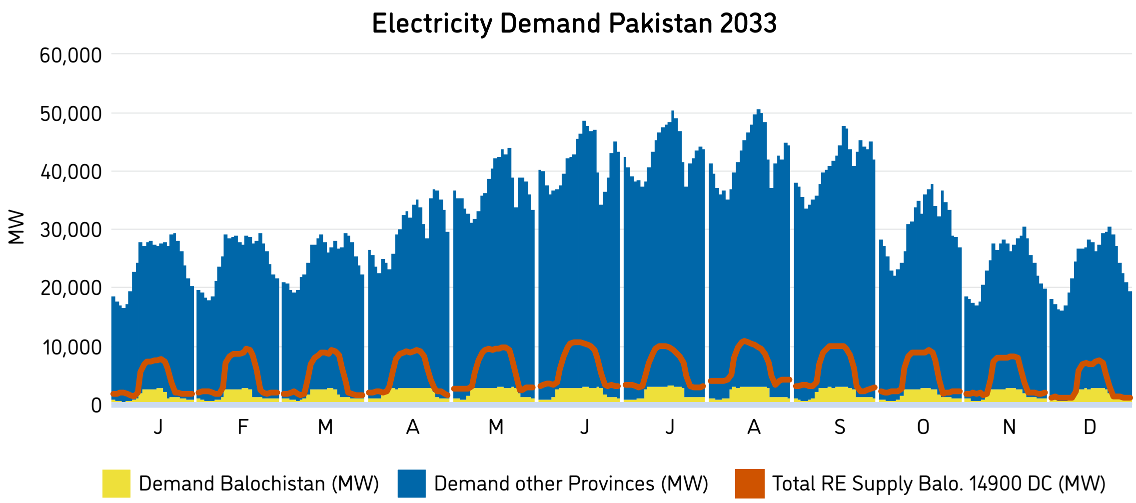
The low remaining supply in certain hours of April and May can be mitigated by shifting HPP electricity production during the day. The simulation for this study does not reoptimize the hourly dispatch for HPP. The hourly distribution of HPP output throughout the day would be adjusted to avoid any disruptive periods, as shown in the following figure at 6 p.m. (18:00).

Figure 5.7: Balochistan RE supply including GW park in April 2033 low-demand forecast



Based on the information provided and assuming the appropriate planning and infrastructure development, it is possible that Pakistan could install around 14 GW of VRE capacity by 2033. This significant addition of VRE has the potential to make a substantial, low-cost, and reliable contribution to the energy supply even in low-demand scenarios and will make a significant contribution to cleaner and more affordable energy.

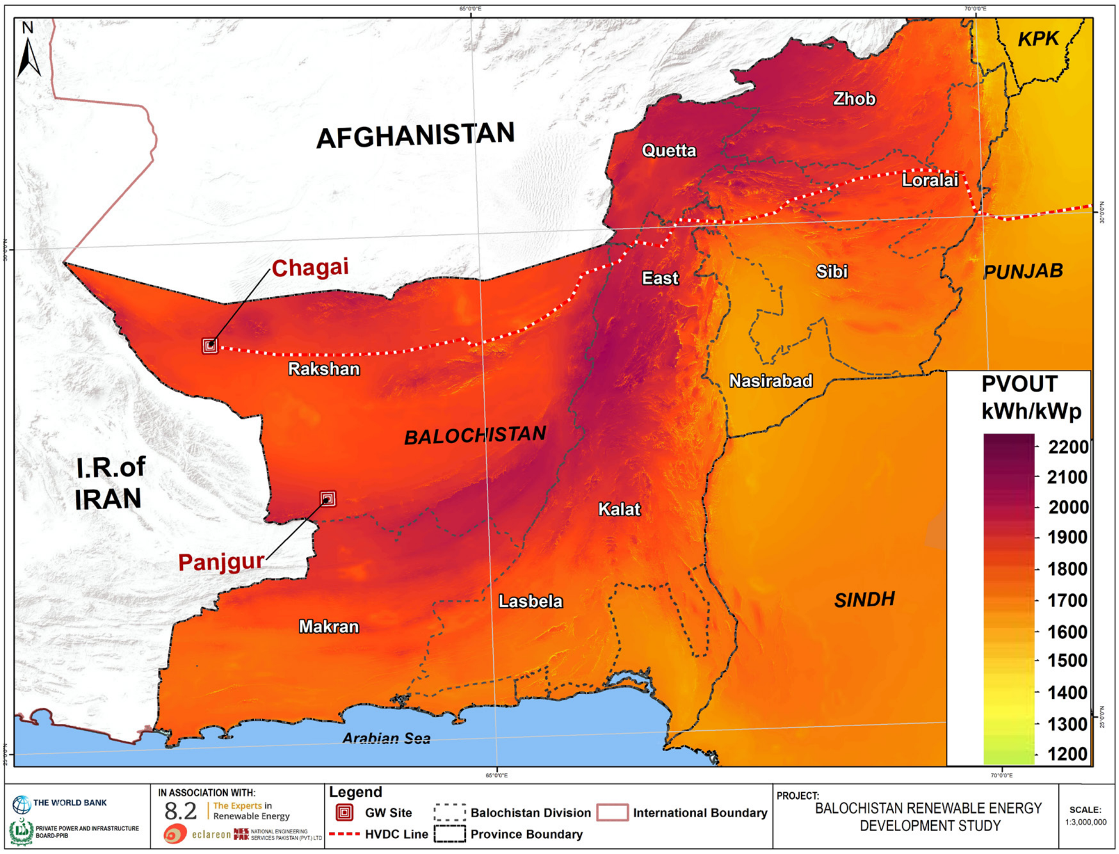
Figure 5.8: Balochistan RE supply including GW park in 2033: expected demand forecast



5.1.4 Grid situation and debottlenecking

The GW park at Chagai would be connected to the Pakistani grid by a ± 800 kV, 4 GW bipole HVDC line with an approximate length of 1,000–1,200 km to Central Punjab. The cost of the line, interconnection, and associated losses are part of the RE park cost. It is assumed that the right of way for such a project can be arranged because of the explicit advantage for the local population.

Figure 5.9: Locations of proposed GW parks



The interconnection line can be developed in two phases:

- US$1.5 billion CAPEX would be required to lay down the line and 2 GW converter capacity during the first phase; and
- US$0.7 billion would be required in the second phase for an additional 2 GW converter capacity.

Electricity can be dispatched with minimal extra effort from Muzaffargarh (World Bank, 2022).

5.2 Electricity Export Options

Pakistan has a few existing and planned interconnections with neighboring countries. The existing grid connection is with Iran for 100MW electricity import. A planned (2025) interconnection with Central Asia through the transmission line known as CASA-1000 (Central Asia--South Asia) would have a 1,000MW capacity.

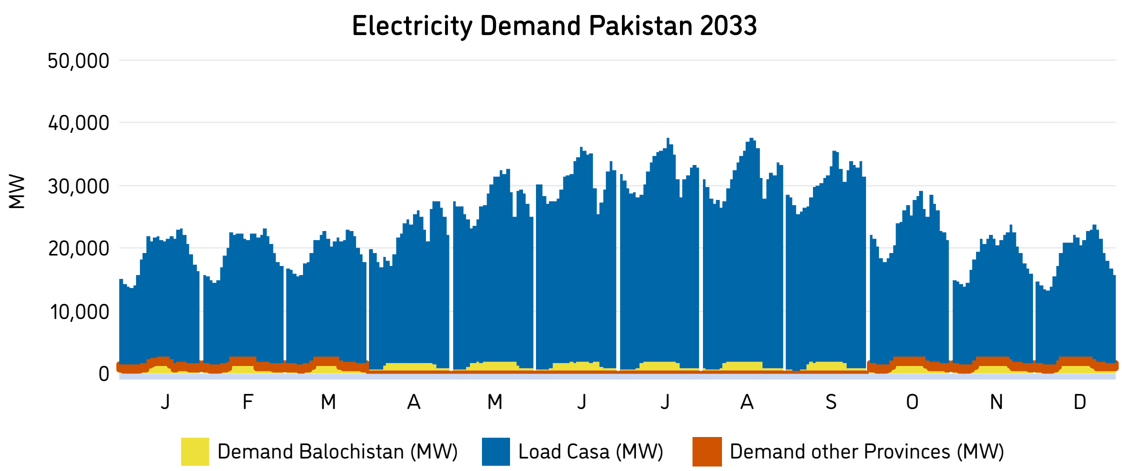
At present, these connections are considered for import only. IGCEP 2022 only includes CASA from 2025 onward. Once the potential of RE supply in Balochistan is exploited, Pakistan will no longer need net imports. However, the connection lines can be used for stabilizing the grid, exchanging electricity with Central Asia and Iran, and optimizing the annual supply mix. In the case of Central Asia, there is a surplus of energy in summer and a deficit in winter, which could be exploited by substituting for the present scenario of outright purchase of electricity in summer an alternative arrangement (or exchange) involving supplying back electricity for the same price in winter. The net result would be a time swap (seasonal exchange) of surplus electricity produced in Pakistan in winter (a time of low demand) for more electricity in summer. The time swap would in effectively shift the bulk of supply from the GW park from winter to summer—when most needed—in other words, transforming electricity imports against foreign reserves into indigenous production.

CASA-1000

As mentioned above, in Central Asia there is a surplus of energy in summer and a deficit in winter, which could be exploited to mutual advantage as just described.

The CASA-1000 HVDC interconnection is a US$1.2 billion project currently under construction that will enable the export of 1,200 MW hydroelectricity from Kyrgyzstan and Tajikistan to Pakistan via Afghanistan. Construction on the project has already begun. The project component in Pakistan and Tajikistan is almost fully developed. To recap, both Central Asia and South Asia experience seasonal load variations. Pakistan's peak load is in the summer, while that of Central Asia is in the winter. The initiative presents an opportunity for Pakistan to utilize the surplus hydropower available in the Central Asian nations during the summer. Furthermore, the same connection can be utilized to export the excess electricity generated by the proposed hybrid GW-scale parks (comprising PV and wind technologies) in Balochistan to the Central Asian nations during the winter.

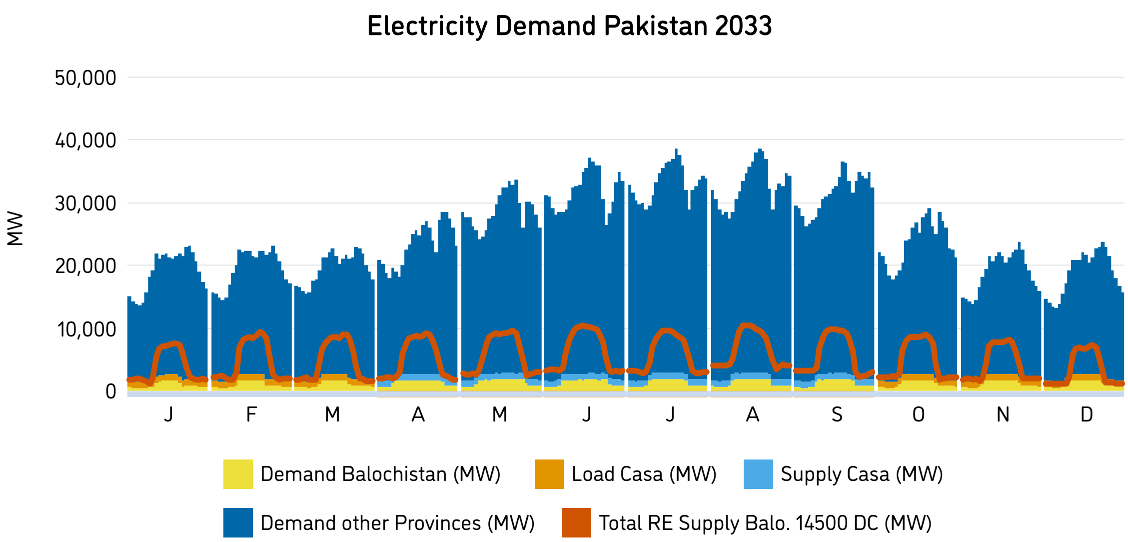
Figure 5.10: 2033 demand profile, including CASA export in winter



Demand source: IGCEP (NEPRA, 2022)

The figure below illustrates the availability of VRE for responding to provincial demand and potential CASA load during winter, eliminating the import needs as discussed above.

Figure 5.11: VRE export potential with 2033 demand profile, including CASA demand in winter



Iran Interconnection:

A 220kV double-circuit transmission line with a length of approximately 140 km from 220kV Polan (Iran) to the 220kV Gwadar grid station exists. The line has a capacity (SIL limit based on length) of above 700 MW, which falls to above 350 MW considering an N-1 contingency. Currently, there is an agreement for import through this line of 100 MW, which can be scaled up to 300 MW. Export of VRE to Iran can be a viable option. The local generation from Gwadar, Panjgur could be exported on existing lines as a first step up to 300 MW. Later, dedicated lines could be built, similar to the currently planned link from Quetta to Zahedan (Iran). Moreover, the locally dispersed anchor loads (mining) can be connected.

Furthermore, the following links for imports from Iran are in the pipeline phase:

- 300 MW import (220 kV) 75 km Gwadar to Polan
- 100 MW (132 kV) Jackigor to Mand
- <5MW import 2 x 20 kV links

However, no further information was available for this study to determine the viability of changing the import into a time swap. This scenario can be explored through mutual discussions between CPPA and their Iranian counterparts.

Additional Opportunities:

Grid connection with the United Arab Emirates involving seasonal exchange of electricity and grid stabilization might also be a feasible option, although this requires an independent analysis. Moreover, the United Arab Emirates has comparatively the same solar irradiance with a lower cost of financing for PV installation, making the export of solar power to the United Arab Emirates commercially unattractive.

5.3 Green Ammonia (Hydrogen)

5.3.1 Worldwide Green Hydrogen Markets and Potential for Pakistan

As per the "REPowerEU strategy" (European Commission, 2022), the EU plans to import 10 Mt of green hydrogen per year by 2030. This is arguably the most specific and reliable announced plan for a green hydrogen market worldwide at the moment, while other green hydrogen markets will certainly emerge on the basis of the Paris 2015 agreement. With the current worldwide efforts toward decarbonization, it is evident that green hydrogen will have an important role in the coming years as a bridge technology, and likely in the long term as well. Many industrialized countries cannot swiftly ramp up their generation capacities for green hydrogen and often lack the required space, or competitive wind and solar resources (to supply the energy needed to split water into hydrogen and oxygen). Therefore the demand for hydrogen in Europe and other regions will have to be supported by worldwide green hydrogen imports.

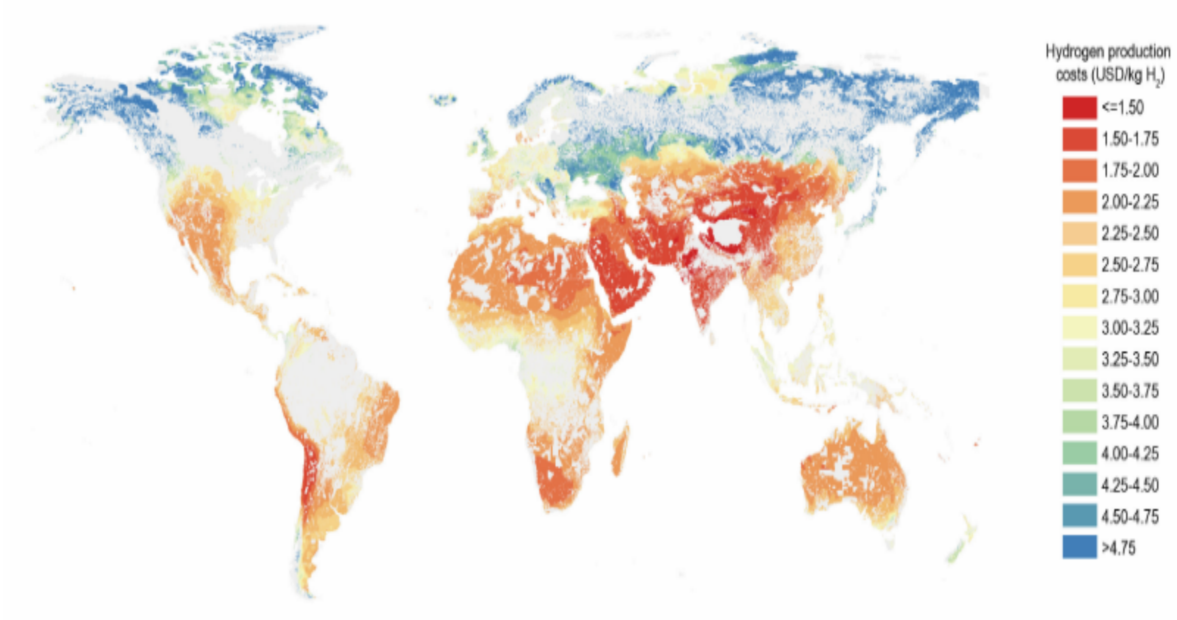
This chapter analyzes whether Balochistan could become one of the export regions for green hydrogen in the next few decades.[50]

50 The study "Pakistan renewable hydrogen energy – Prefeasibility study" by the ADB (October 2021) gives Pakistan a low chance of participating in the green hydrogen export market. However, this judgment is based on a very general qualitative analysis by stating that other countries are better suited in terms of VRE availability and proximity to markets like the EU.

A considerable amount of analysis is currently underway on the potential for and cost of green hydrogen in various locations to identify those countries currently most likely to become the chief exporters (and on what other countries might have to do to attain such a position). Balochistan is one of the most promising areas for exporting hydrogen in terms of the availability of both wind and solar power. However, the map only accounts for generation costs, so for the EU market, candidates like Spain and Morocco which might be connected through the pipeline might still achieve more competitive overall costs for green hydrogen for Europe. Others like Chile or some parts of Australia also have excellent wind and solar resources.

The figure below illustrates hydrogen production cost from PV and wind hybrids at a minimum load of 40 percent by 2030 (estimate).

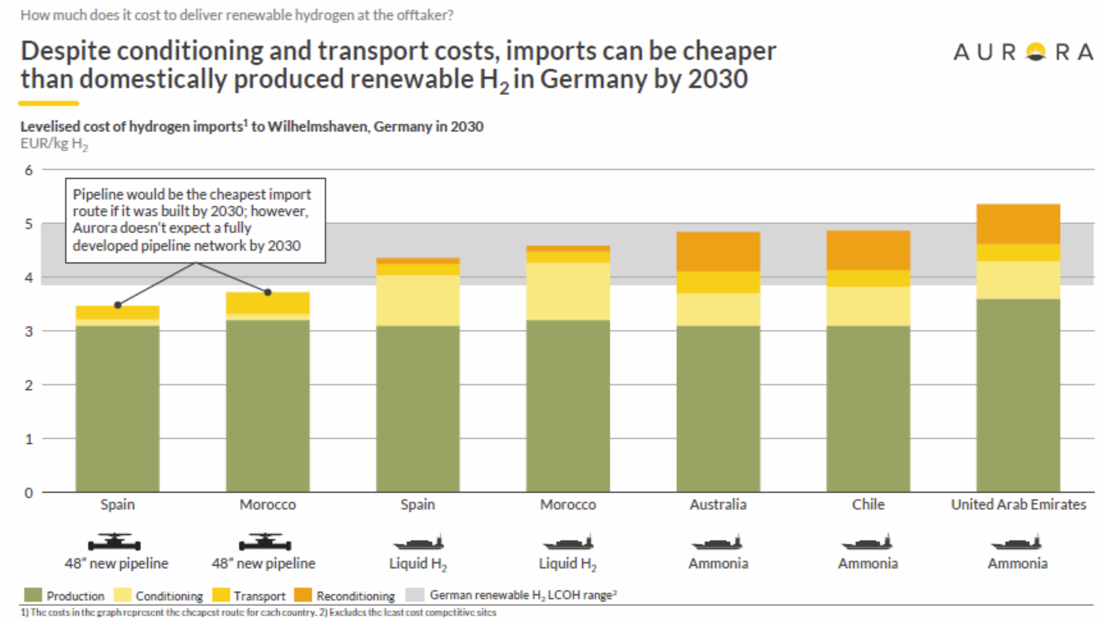
Figure 5.12: Hydrogen production cost from PV and wind hybrids



Source: (IEA, 2022)

The chart below shows that, due to high transportation costs of compressed hydrogen, ammonia is the most feasible transportation vector for larger distances as it has higher reconditioning costs but lower specific transportation costs. This also means that for larger distances, this conversion to ammonia is required in any case, and the cost implications of increasing the transportation distance by several thousands of kilometers are then of less relevance.

Figure 5.13: Estimated cost breakdown for import of green hydrogen from different countries



Source: (Aurora Energy Research, 2023)

Overall, if Balochistan is to become a green hydrogen exporter, the relatively high distance to green hydrogen markets such as the EU as well as a challenging infrastructure environment within Balochistan (remoteness, lack of general infrastructure, security issues) need to be offset. This could be achieved by a very competitive VRE generation profile (such as in regions like Chagai) as well as favorable financing conditions—the latter being a crucial point in the case of Pakistan. Since it is a country that is severely affected by climate change (as the floods in 2022 showed), Pakistan might have a good chance to achieve specific bilateral or multilateral financial and technical assistance from donor countries to implement such a large infrastructure project under favorable terms.

5.3.2 Green Ammonia Plant for Balochistan

The following sections lay out how a potential green hydrogen plant could look in Balochistan. Due to the need for export, Gwadar is selected as the export port as it has the highest level of infrastructure and development in the province as well as an ambitious masterplan for further development. Moreover, the production of hydrogen necessitates substantial quantities of water, a resource that is limited in Balochistan. However, one viable and socially as well as environmentally sustainable solution is the extraction of water from seawater through desalination. As green hydrogen needs to be generated through solar and wind power only[51] and as the economic viability of green hydrogen depends very much on an excellent VRE generation profile, the corresponding generation plant should be located in the Chagai region (see Chapter 5.1). The closer Panjgur area would be an alternative for the VRE site, with a slightly less favorable VRE generation profile (albeit less length of grid line required).

As the green hydrogen will have to be transported by ship to distant markets like the EU, green ammonia will be the more cost-efficient transportation vector, so the green hydrogen should be converted to ammonia before being exported to vessels. The cost and technical parameters of such a sample plant are estimated by using the freely available tool HySupply.[52]

51 Other RE technologies are permissible, but as they have to be built specifically for this purpose as per EU regulation, and have to be cheap to remain competitive, solar and wind are virtually the only ones that make sense for green hydrogen at the moment—not only for Pakistan, but worldwide.
52 HySupply Ammonia Analysis Tool V1.0 by the University of New South Wales, Australia.

This results in the following required infrastructure:

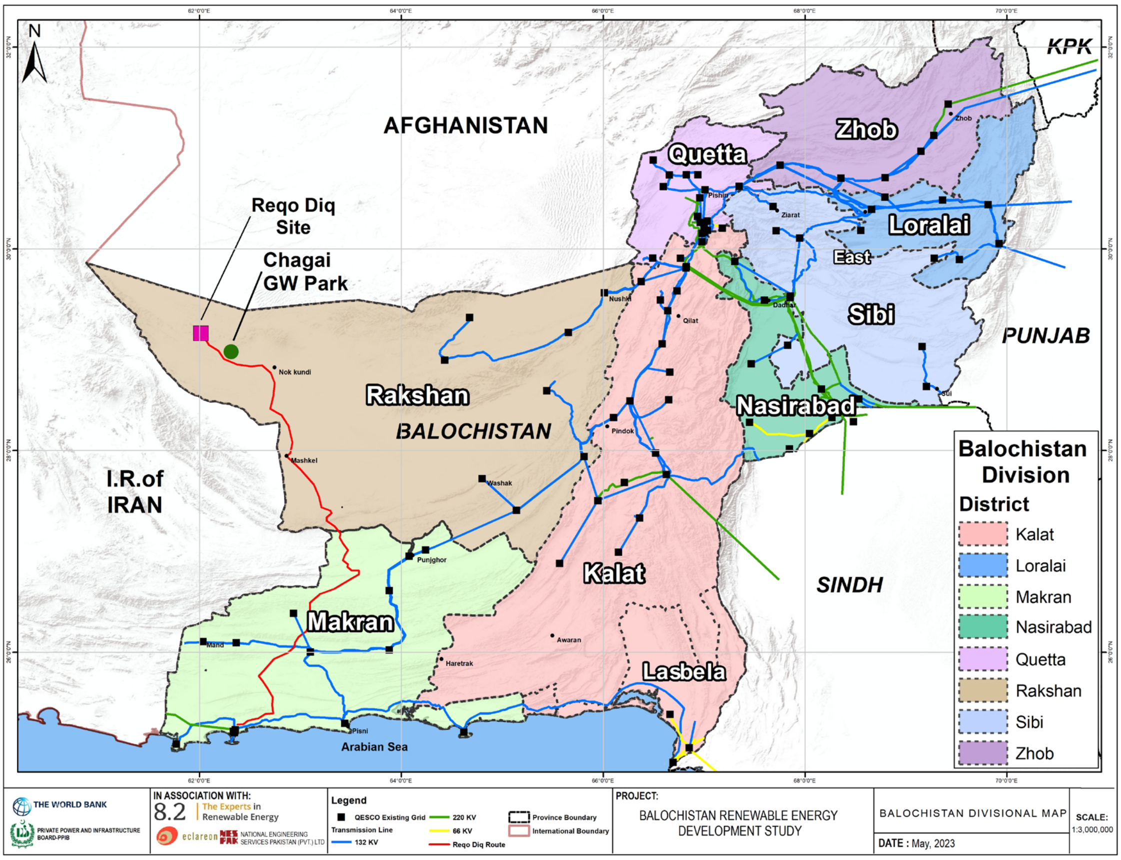
- A wind-solar hybrid plant in Chagai (or Panjgur);
- Transmission lines for bringing the power to Gwadar;
- An electrolyzer plant close to Gwadar port, including a desalination plant;
- A plant for synthesizing the ammonia on the same site (Haber-Bosch process); and
- An ammonia export terminal at Gwadar port

5.3.3 Energy supply for green ammonia production

The energy for this sample plant would come from the Chagai region. The specifics of such a plant have been laid out in **Chapter 5.1 Gigawatt Hybrid Park.** For example, if a GW plant is developed at Chagai, 1–2 GW of this plant or more could be dedicated to the generation of green hydrogen at Gwadar.

To bring the 1 GW of power to Gwadar, new transmission lines are needed. A 500 kV AC line[53] from Chagai to Gwadar is therefore required, with the addition of a 500 kV substation to divide the line into two segments and avoid stability issues. The 132/11kV Panjgur substation would be a good site for the 500 kV substation to allow for further grid integration.

Figure 5.14: Proposed connection from Chagai VRE park to green ammonia plant in Gwadar



53 A double-circuit QUAD bundle AAAC Greeley conductor would be recommended.

5.3.4 Sample Green Ammonia Plant Sizing and Costing

Based on the input factors outlined earlier, a sample plant has been sized and simulated in a simplified manner, utilizing the basic assumptions mentioned regarding its location.

The size of the plant chosen was 500,000 tons (t) of green ammonia per year, equivalent to roughly 150,000 t of green hydrogen which would be equivalent to 1.5 percent of the estimated import amount of the EU for 2030 (see above). The corresponding VRE plant capacities are 1,000 MW of PV (one-axis tracking) and 750 MW of wind. As the ammonia synthesis needs to run at a constant throughput level, a balancing power source is also required (34 MW at maximum); for this, BESS or wheeling of hydropower through a connection at Gwadar was assumed. The project's total capital cost (including power plant, transmission lines, electrolyzer, ammonia sensor synthesis, and desalination) amounts to approximately US$4 billion.

The following charts and tables illustrate the input parameters, main results, and a breakdown of the capital cost and levelized cost of the resulting green ammonia.

The modeled levelized cost of hydrogen (LCOH) amounts to US$4.05/kg, although this depends strongly on the cost assumptions for electrolyzer and others and cannot be compared directly to other studies. For reference, the IEA in its Hydrogen Outlook (IEA, 2022) gives a worldwide LCOH range for green hydrogen of US$4–9/kg for production via electrolysis with renewable electricity.

However, as these cost estimates are so sensitive to the technology cost assumptions of electrolyzers, and the ammonia-synthesis plant, a direct comparison with LCOH estimates for other locations from other studies does not make sense. Nevertheless, another approach can be taken for benchmarking between countries—the single most important cost factor is the cost of RE electricity. This is for solar and wind-powered plants defined mostly through the available solar and wind resources and more specifically the combined load factor of wind and solar that can be achieved in a location. Based on this background, different locations worldwide can now be compared based on the availability of wind and solar resources.

For example, Chagai in Balochistan achieves load factors for solar PV and wind of 26 percent and 45 percent, respectively, and through hybridization 56 percent. The best sites in Morocco, close to the West Sahara border (another promising green hydrogen candidate close to the EU market) achieve 30 percent and 54 percent, respectively, for PV and wind power, and can achieve a hybrid load factor of 56 percent with 20 percent less installed capacity. Assuming the same cost assumptions for PV and wind CAPEX and operational expenditure (OPEX) in both countries, this difference in resources translates into the levelized cost of electricity (LCOE) of the combined PV-wind hybrid plant being 20 percent cheaper for Morocco. Assuming LCOE constituting 33 percent of the final resulting LCOH as stated above, this means that hydrogen could be generated in Morocco at seven percent less cost compared to Balochistan, based solely on the availability of resource. This result will change if an alternate use of the curtailed VRE electricity can be found, which is the case for Chagai. However, a grid connection from Chagai to Gwadar will be an additional cost.

Meanwhile, a comparison with the United Arab Emirates, which is another economy venturing into green hydrogen export, yields load factors of 34 percent based on solar PV only. With costs comparable to Chagai, assuming the same terms of financing, the lower load factor results in a lower nonenergy CAPEX efficiency. Assuming nonenergy CAPEX is around 33 percent of the total cost of green ammonia and the CAPEX efficiency is 40 percent lower, the cost advantage of the Chagai region would be some 13 percent over the United Arab Emirates.

Even if some locations are more economical in this analysis, their overall potential might be limited, especially for wind, which is often limited to certain corridors. Even if Balochistan turns out to be more expensive than Morocco, UAE, and Australia, for the worldwide green hydrogen market to be developed, there should still be a large scope for Pakistan.

Table 5.4: Salient features of a sample green hydrogen plant

Key Input Summary		
Parameter	Unit	Value
Ammonia plant capacity	kT/a	500
Ammonia plant power demand	MW	23.40
Air separation unit capacity	TPD	1128
Air separation unit power demand	MW	10.81
Hydrogen output	TPD	242.3
Nominal electrolyzer capacity	MW	1,010
Electrolyzer system oversizing	%	100%
Generator type		Hybrid
Nominal solar farm capacity	MW	1,000
Nominal wind farm capacity	MW	750
Hybrid generator split	% Solar	57%
	% Wind	43%
RE plant oversizing	%	68%
Total nominal power plant capacity	MW	1,751
Hydrogen storage capacity	Kg	25,000
Key Results Summary		
Parameter	Unit	Value
Average power plant capacity factor	%	34%
Average time electrolyzer is at max capacity	% of 8,760 hrs/yr	62%
Average total time electrolyzer is operating	hrs/yr	8760
Electrolyzer capacity factor achieved	%	88%
Energy consumed by electrolyzer	MWh/yr	4,774,917
Energy consumed by ammonia/ASU plant	MWh/yr	271,651
Energy used to charge battery	MWh/yr	0
Time ammonia plant is at max capacity	% of 8,760 hrs/yr	99.98%
Ammonia plant annual capacity factor achieved	%	99%
Average total time ammonia plant is operating	hrs/yr	8760
Hydrogen production	TPA	148,545
Nitrogen production	TPA	411,408
Ammonia production	TPA	494,863
Excess power generated (curtailed or sold to grid)	MWh/yr	189,421
Levelized cost of hydrogen	US$/kgH2	US$4.05
Levelized cost of ammonia	US$/kgNH3	US$1.22

Typically, modern ammonia tanker ships can carry between 10,000 and 50,000 metric tons of ammonia. A production facility of this size would require at least nine transports per year.

The overall cost of ammonia can be decreased by considering the value of the curtailed electricity, although this factor does not significantly impact the cost outcomes. In this scenario, approximately 190,000 MWh per year are not utilized by the plant and could potentially be sold to the grid at a rate of US$0.05/kWh, resulting in a LCOH reduction of US$0.06/kg.

Table 5.5: Approximate capital cost breakdown for a 500 kT/a green ammonia plant

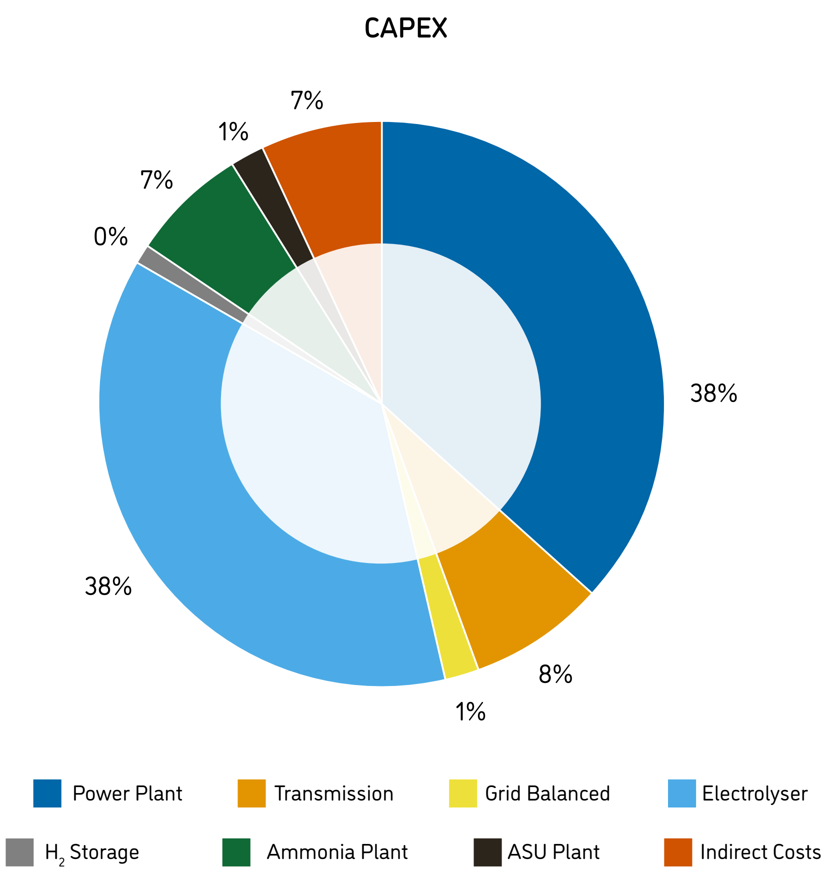
Component	CAPEX (US$, millions)
Power plant	1,566
Transmission	324
Grid connection	-
Grid balanced	44
Electrolyzer	1,578
H2 storage	7
Ammonia plant	296
ASU plant	50
Indirect costs	282
Additional costs	-
Total capital cost	**4,147**

Figure 5.15: Approximate capital cost breakdown for a 500 kT/a green ammonia plant

Table 5.6: Approximate levelized cost breakdown for a 500 kT/a green ammonia plant

	LCONH3 (US$)	LCOH (US$)
Power plant CAPEX	0.27	0.90
Grid OPEX	-	-
Trans. CAPEX	0.06	0.19
Balance tech CAPEX	0.01	0.03
Elec. CAPEX	0.27	0.91
H_2 Storage CAPEX	0.00	0.00
Indirect Costs	0.05	0.16
NH_3 CAPEX	0.05	0.17
ASU CAPEX	0.01	0.03
Power plant OPEX	0.05	0.17
Balance tech OPEX	0.26	0.88
Grid OPEX	-	-
Elec. OPEX	0.08	0.27
Others	0.10	0.34
Total	1.22	4.05

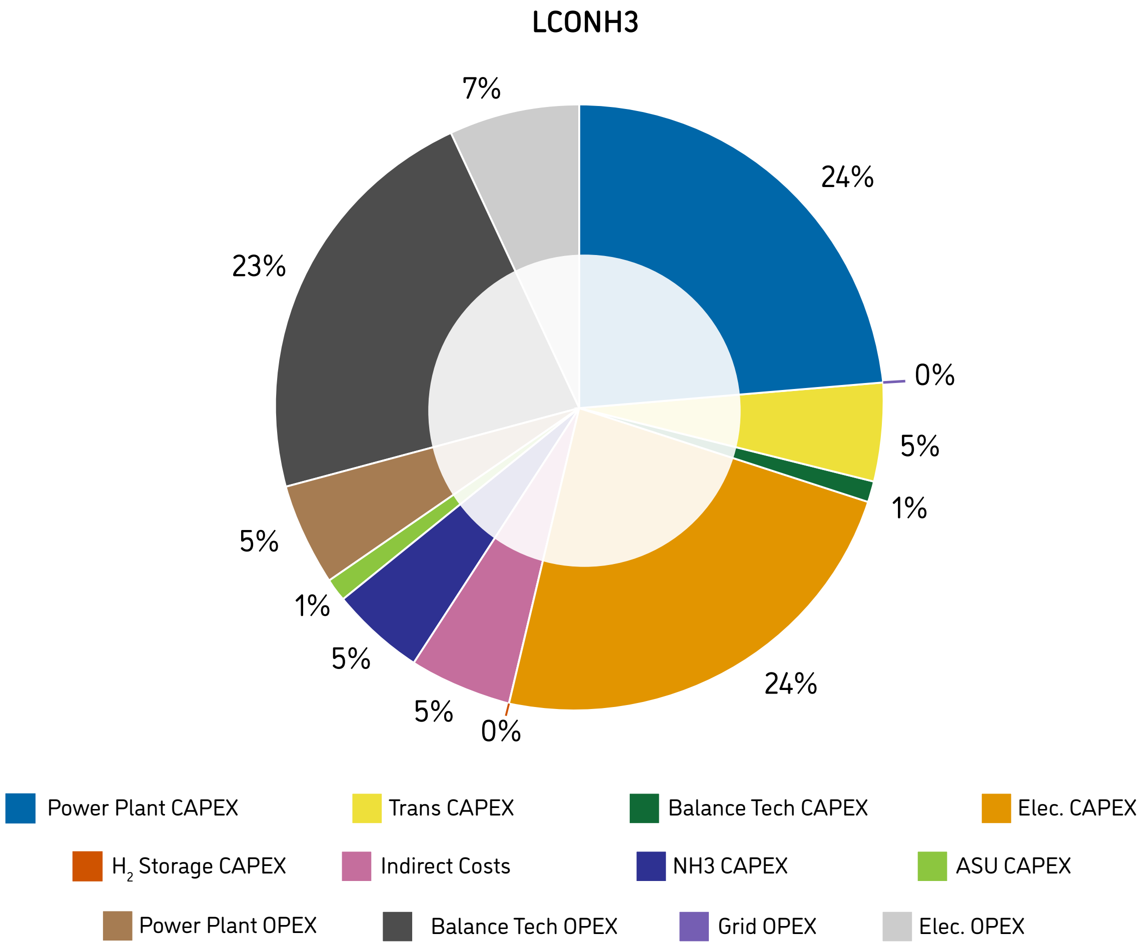
Figure 5.16: Approximate levelized cost breakdown for a 500 kT/a green ammonia plant



5.3.5 Conclusion

Balochistan has excellent VRE potential, which is the most important factor for the cost-efficient generation of green hydrogen.

A sample plant for green hydrogen has been described above; it would cover a plant of 1 GW solar and 750 MW wind in Chagai or Panjgur region, a high voltage line of 1 GW capacity and approximately 500 km in length toward Gwadar, and an electrolyzer, desalination, and ammonia-synthesis plant in Gwadar. Total costs would amount to about US$4 billion; the plant would produce about 148,000 t of green hydrogen per year, which would be converted to 494,000 t of green ammonia.



6. Financial and Economical Evaluation

6.1 Financial evaluation

6.1.1 Utility scale

The least-cost principle of the National Electricity Policy 2021 (MoE, Power Division, 2021) was set as the prime selection criterion for all new capacity additions. According to the results of the VRE Locational Study (World Bank, 2021), it is anticipated that all PV plants implemented in Balochistan can provide electricity at a 14 percent lower cost compared to any other province. The locational study examined over 80 locations consistently, and although there were slight changes in the assumptions regarding cost and financing terms, the ranking of the sites remains unaffected. Therefore, until clarified through a competitive bidding process, the relative results from the VRE locational study can be applied in the current study.

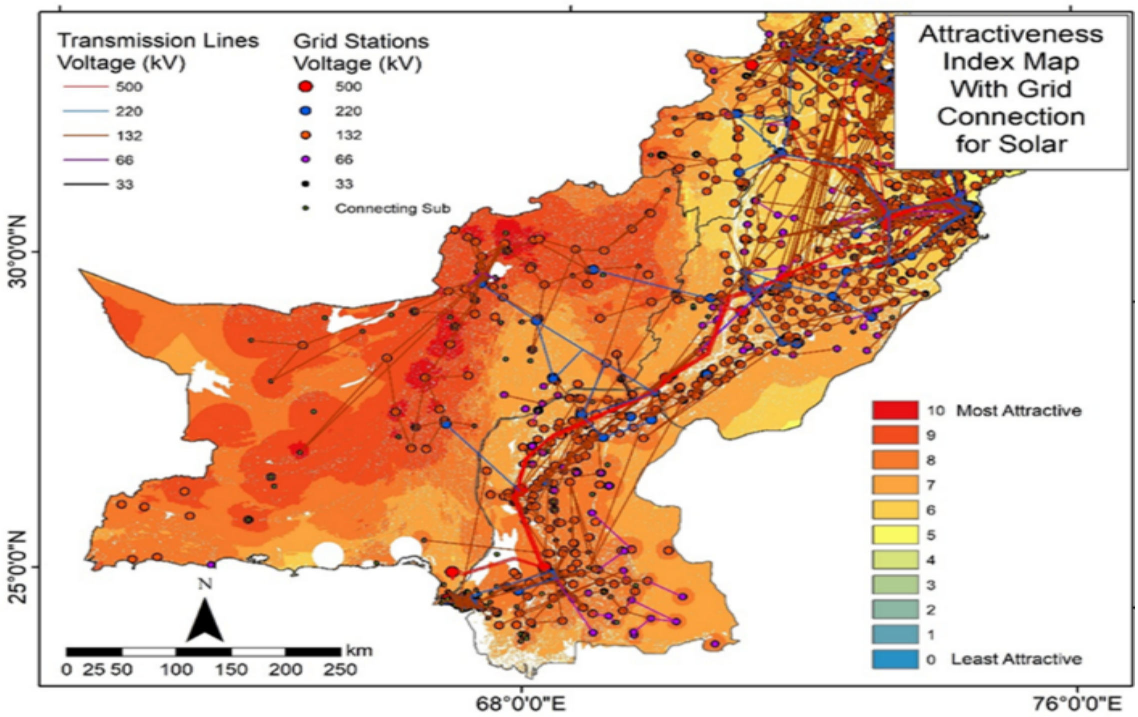
Table 6.1: Approximate cost breakdown

	Capacity PV	Sum of PPA x Capacity	Weighted average PPA	Weighted average PPA
Unit	MWp	Cts	Cts/MW	
Balochistan	2,516	11,836	4.70	4.70
KPK	280	1,740	6.22	
Punjab	1,720	9,266	5.39	5.47
Sindh	2,930	15,946	5.44	
Total	7,446	38,789	5.21	

Source: VRE locational study (World Bank, 2021).

Higher irradiation, less air pollution, and lower temperatures can contribute to higher expected output for solar power plants. These factors can positively impact the efficiency and performance of solar panels, resulting in increased electricity generation in Balochistan in comparison to other regions, such as Sindh and southern Punjab, that have lower irradiance. The increased output would translate into a lower expected PPA cost for the same installed capacity considering the same development, installation and operation cost of the plants for each province. Transportation costs for PV systems would be insignificant since the components can be transported in small units. This allows for easy logistics and installation, regardless of the region. Moreover, utility-scale solar plants are usually connected to the higher voltage grids, such as the 220 kV grid, which minimizes expected losses during grid evacuation.

Figure 6.1: PV cost advantage, Balochistan

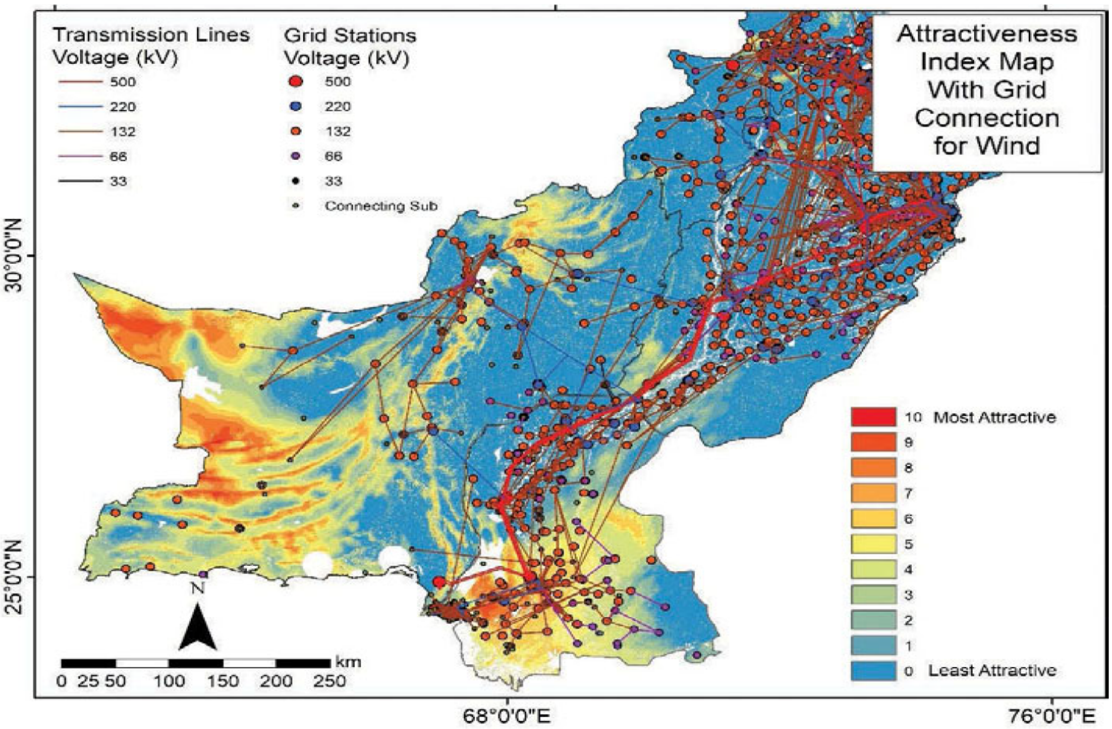


Source: (World Bank, 2021)[54]

Balochistan has the highest DNI of Pakistan as presented in Section 2.3.4 (Concentrated Solar Power Technology), making the region the most favorable for CSP technology. Moreover, the locations best suited to wind energy are mostly in Balochistan. The wind corridor that has been most extensively utilized thus far is Jhimpir in the Sindh region, which offers better accessibility but slightly lower wind resources.

54 The most cost-attractive locations were all in Balochistan: 1 point of attractiveness score corresponds to US$0.006/kWh expected cost. With an overall cost expectation of US$0.04–0.06/kWh a difference in attractiveness of 2 points results in 20–30 percent expected cost difference.

Figure 6.2: Wind cost advantage, Balochistan



Source: World Bank, 2021

In conclusion, the feasibility of implementing 4.8 GWp of utility-scale PV in Balochistan is in no doubt. Balochistan has available land, sufficient local grid capacity, and export capacity. Additionally, the region's characteristics, such as higher irradiation levels and potentially lower expected costs, make it an attractive choice for PV projects. The least-cost sites in Balochistan can be shortlisted by the NTDC and CPPA for competitive bidding after conducting a comprehensive assessment of the potential sites. This would involve evaluating factors such as solar resource potential, land availability, grid connectivity, environmental considerations, and any other relevant criteria.

6.1.2 Mining

The actual demand for electricity in the region is expected to exceed the load forecasts as it would depend on the utilization of VRE resources by the mine operators. In the case studies analyzing the feasibility and financial advantage of VRE as a fuel-saving instrument, a significant cost advantage was determined. These case studies can be used as an example for the majority of the mining sites in Balochistan.

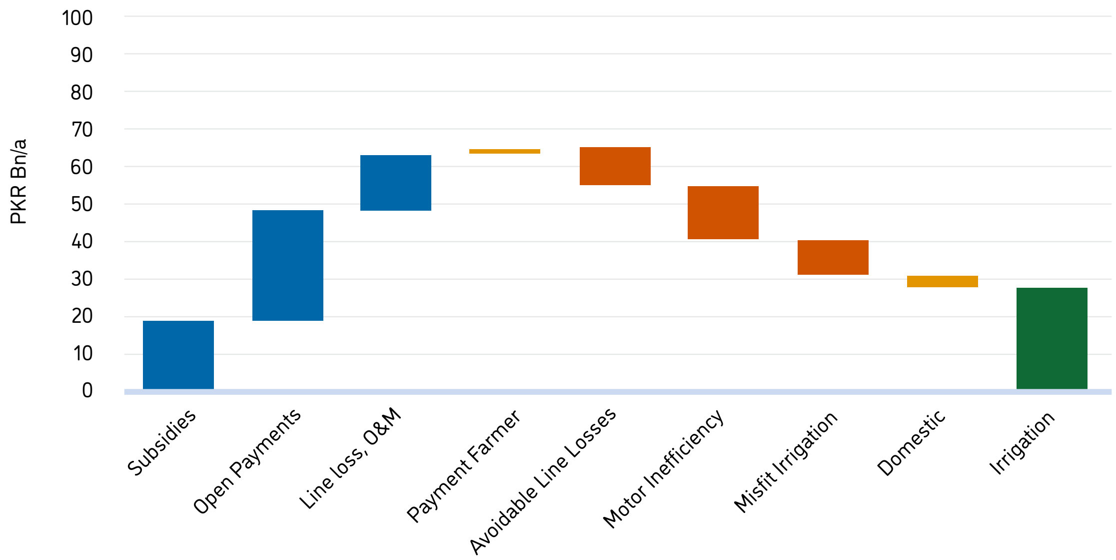
The case studies indicate potential savings of up to 65 percent in electricity supply costs for mining operations. While the actual savings may be lower due to factors such as the use of untaxed Iranian oil as fuel, the introduction of PV can still result in substantial reductions in supply costs and address logistical challenges. The use of PV with BESS, CSP or geothermal, if available, can provide a stable and predictable source of electricity, mitigating the risks associated with fuel price fluctuations and supply chain complexities.

6.1.3 Distributed PV

QESCO incurred a financial loss of US$340 million in 2022. This loss is projected to increase to US$492 million in 2028 at a low forecast of 5,472 GWh of electricity consumption. The purchase price of electricity is given as US$0.1 per kWh, of which QESCO is only recovering US$0.01 per kWh against the purchase price. The difference is attributed to two factors: the subsidy provided to the farmers and nonpayment by farmers.

In a feasibility study for solarizing tube wells in Balochistan (NESPAK, 8p2, 2020) a detailed analysis was conducted. It established the origin of the funds providing electricity to agricultural consumers in Balochistan, and the uses to which the electricity was put: 99 percent of the electricity was paid for by the provincial and federal government, or remained unpaid; and roughly 50 percent of the electricity was wasted in line losses, inefficient motors and excessive irrigation during the off-season.

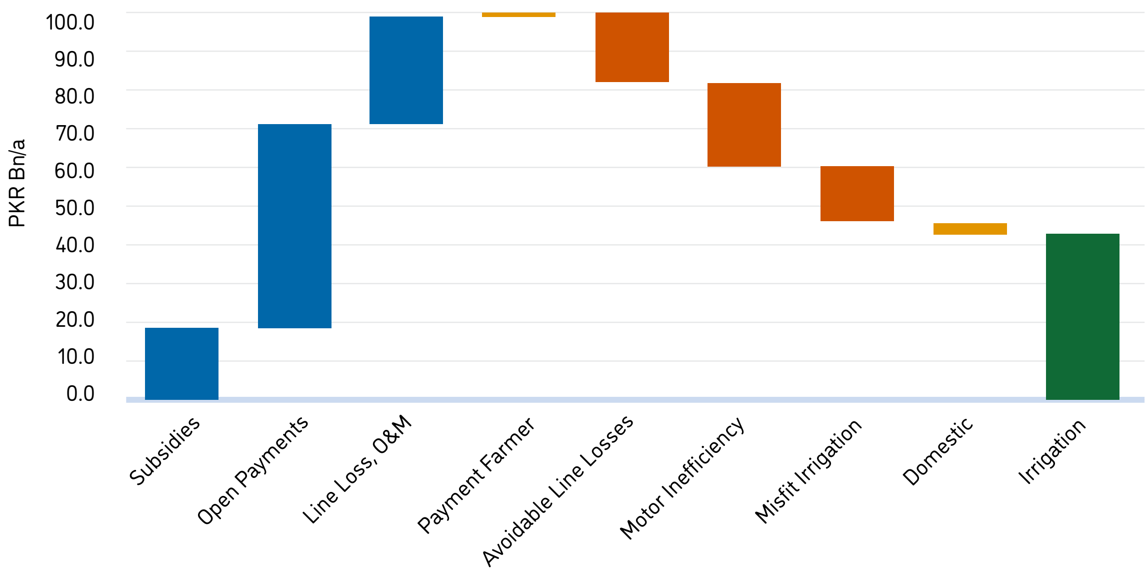
Figure 6.3: Funding and usage analysis of agriculture feeders in Balochistan 2018/19



Source: (NESPAK, 8p2, 2020)

The figure below shows updated numbers. The electricity usage from tube wells remained roughly constant, however, the cost of electricity increased. Approximately half the electricity generated is not put to productive use.

Figure 6.4: Funding and usage analysis of agriculture feeders in Balochistan 2022/23



If the recommendations provided in the feasibility study (NESPAK, 8p2, 2020) are followed, the gross energy demand is expected to fall by approximately 50 percent, resulting in an estimated demand of 2,792 GWh for 2028. The payback of needed investment in DPV and efficient motors and pumps was estimated at 3.5 years; or 3.8 years if the farmers were charged nothing for the electricity they consume. The assumptions were updated for this study, such that the payback period has improved to 3.2–3.7 years depending on finance assumptions and payments from farmers.

The installation cost of a DPV solution including energy efficient motors, pumps, and the necessary control equipment to ensure payment collection is US$0.08/kWh in PPA mode, which is higher than utility-scale plants, but less expensive than grid supply.

Implementing this solution would reduce the current loss of US$492 million to US$195 million without requiring any additional payments from the farmers.

The proposed solution improves the electricity supply significantly and reduces fuel and O&M costs, as well as any additional expenses borne by the farmers, by approximately US$0.06/kWh. This means that farmers would be able to cover the cost of the PV supply without being financially worse off than today. The solution also offers precise monitoring of individual electricity usage and the ability to remotely shut down the electricity supply in the event of nonpayment.

Summing up, the proposed DPV solution offers a more cost-effective and reliable electricity supply while providing opportunities for financial savings and improved control over energy usage.

6.1.4 GW Park

The proposed GW solution would provide electricity at competitive costs ranging from US$0.065 /kWh to US$0.082/kWh based on the 2023 cost framework. These cost savings would benefit the people of Pakistan by providing more affordable electricity.

The table below shows that even with only 17.7 percent loading of a 4 GW HVDC line, the costs of the proposed solution are comparable to larger hydropower project opportunities offering significant cost savings per kWh (US$0.071 versus US$0.08 for hydro). At full utilization and a high capacity factor, the cost of supply, including grid connection, would fall below US$0.065/kWh.

Table 6.2: Financial snapshot of GW Park opportunity

Economic output	2 GW	4 GW	6 GW	7 GW	8 GW	9 GW
PV MWp	1,000	2,000	3,000	4,000	5,000	6,000
Wind MW	1,000	2,000	3,000	3,000	3,000	3,000
Production surplus %	0%	9%	2%	5%	8%	13%
Grid utilization %	18%	32%	52%	57%	61%	64%
Total CAPEX (US$, millions)	3,220	4,964	7,506	7,965	8,529	9,094
OPEX incl. fuel (US$, millions/year)	2,354	1,988	1,483	1,357	1,262	1,202
RE PPA + HVDC cts/kWh	8.24	7.10	6.66	6.46	6.50	6.66
NPV vs. HPP CPPA (US$, millions)	915	2,504	4,566	5,266	5,568	5,550

Table 6.3: Comparison: GW HPP and VRE

Criteria	HPP	VRE Hybrid	Comment
Cost	Medium	Medium	Similar cost
Time to market	6+ years	3 years, phasing possible	VRE much quicker, thus allowing higher IRR
Availability risk	Medium in spring	Low	All HPP in country depend on the same water inflow
Dispatchability	In season	Very low	
Cluster risk	High	Low	All HPP in country depend on the same seasonal water availability
Environmental impact	High	Low	VRE does not require large resettlement

6.1.5 Export

Excess energy can be exported to other countries at a competitive price. In the case of CASA, the import price is stated to be US$0.06/kWh, slightly lower than the US$0.065/kWh from the GW opportunity. Depending on the actual supply and demand situation in Pakistan, a valid option may be to effectively swap electricity (purchase in summer to offset sale in winter) rather than to buy in summer months only.

However, in the case of export to Iran or the United Arab Emirates, it is unlikely that the negotiated price will be financially attractive. Iran does not experience significant demand for energy close to the border; meanwhile, the United Arab Emirates has its own resources, with PV power costing less than US$0.03/kWh and CSP costing around US$0.07–US$0.08/kWh.

6.1.6 Hydrogen

The case study reveals a potential cost advantage over some international locations for hydrogen production. An LCOH of US$4.05/kg in Balochistan seems feasible, which could have an advantage over UAE of some US$0.5/kg due to a better capacity factor using wind and solar PV. In addition, global demand might exceed supply for the foreseeable future so that even without cost leadership a healthy export margin might be obtained.

6.2 Finance

The utility-scale opportunities can be financed in the same manner as any other RE project in Pakistan. Several developers are involved in projects in Balochistan, and their main concern is not financing, but rather the allocation of land and the initiation of a competitive bidding process. In order to ensure bankability, it is important for the government of Balochistan to participate in the project by providing land in exchange for equity. By providing land, the government would become a stakeholder in the project and share the risks and rewards associated with it. This would enhance the project's bankability and attract further investment.

For DPV and mining projects, the credibility of the off-taker is an important consideration. One option is for the government of Balochistan to provide risk guarantees for the projects. This means that the government would guarantee the off-take of the power or minerals produced, ensuring that the developers have a reliable purchaser for their output.

Another option is to encourage local consortia or investors to fund the projects. Involving local stakeholders—such as businesses, organizations, and investors—in funding the projects not only increases local participation but also improves the credibility of the off-taker. Local consortia would have a vested interest in the success of the projects and would be motivated to ensure efficient payment collection.

If the State Bank of Pakistan provides refinancing support to financial institutions, it can lower the cost of borrowing and facilitate access to capital for the projects, thus encouraging local equity investment and making financing more accessible for developers.

A longer-term GW park or green hydrogen plant would require a consortium of large national players like PPL, Engro Energy, or Hubco with the government of Pakistan and international technology providers. Financing should include the necessary grid connections that would be a major part of the total cost. The NTDC could pay back the grid investment over time, thereby taking over the grid infrastructure from the investor.

No savings in GHG emissions have been factored into the analysis. A global market for GHG emissions savings is expected to develop, further reducing the net cost.

The governments of Balochistan and Pakistan can indeed engage in lobbying efforts at international forums and with development banks to secure concessional finance for project opportunities in Balochistan. Lobbying at these forums can help raise awareness about the region's investment potential and development needs, attracting the attention of international development institutions and financiers such as the World Bank, Asian Development Bank, and other regional development institutions.

Dedicated government-to-government investment or finance agreements would probably be needed to finance the US$16 billion, which is the identified investment volume for the next 10 years. Similar arrangements have been successful: with China (in the form of CPEC, the China–Pakistan Economic Corridor) and also with the Kingdom of Saudi Arabia. A dedicated approach with European counterparts might be highly feasible for green hydrogen. The GW investment opportunity in Chagai or Panjgur might attract government-to-government investments; it might also be an option to export winter electricity to Central Asian countries.

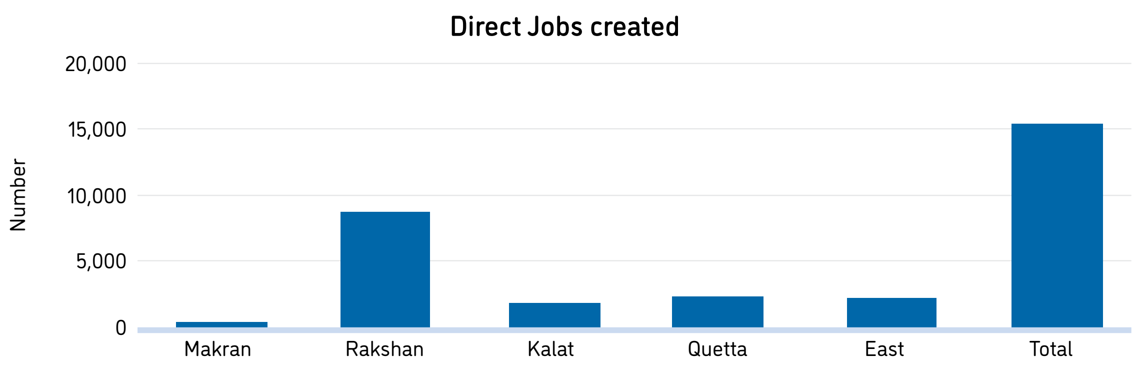
6.3 Economic Evaluation

The detailed economic analysis revealed a significant impact of the potential VRE plants on jobs and GDP development in the province.

Local stakeholder perspective

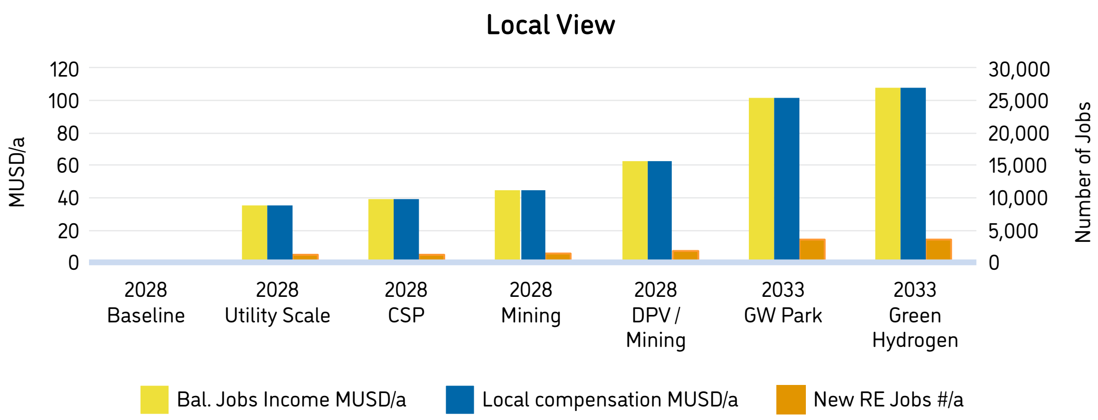
The purchasing power of the local stakeholders improves as a consequence of additional employment, and the corporate social responsibility benefits of the developers. A reliable and consistent electricity supply would have several positive impacts on agricultural practices and the livelihoods of farmers in Balochistan. More than 15,000 direct jobs could be created in the longer term. Most of the jobs would be created close to the VRE plant sites. In the event of a GW park in Rakshan, this would create substantial job opportunities.

Figure 6.5: Direct job creation by 2033 by region



Total jobs created include direct and indirect jobs created. Please see Annex B.2 (Impact on Job Creation) for details. In addition, the creation of further jobs through local manufacturing can be expected once a market development is established. This should at least cover less sophisticated structures and building materials. These effects would be in addition to the quantitative effects analyzed in this study.

Figure 6.6: Total jobs and compensation by scenario – cumulative



By prioritizing local hiring and implementing training initiatives, the development of RE projects in Balochistan in the next decade can directly contribute to the region's socioeconomic development. It can provide long-term employment opportunities, skill development, and capacity building, enabling local communities to actively participate in and benefit from growth of the RE sector.

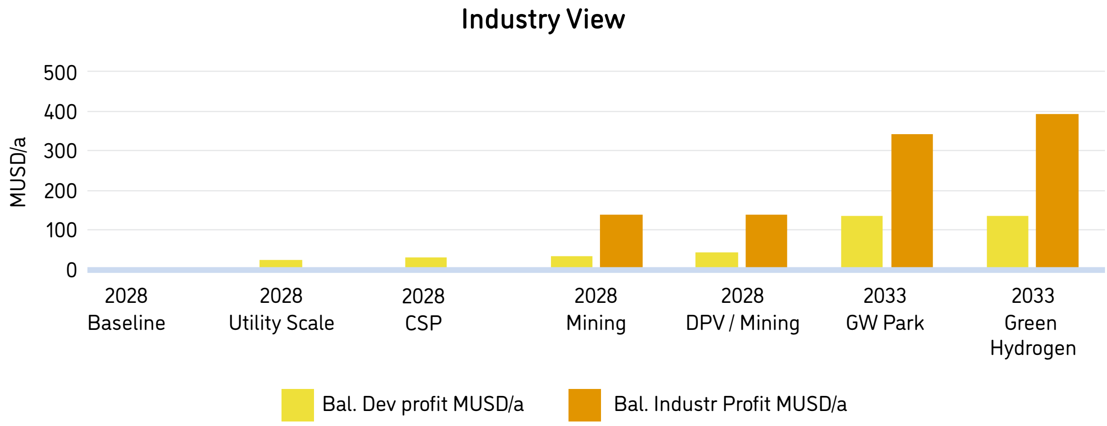
Industry Perspective

The development of RE projects and the mining industry in Balochistan can bring significant benefits to the industry itself and create various business opportunities for local construction firms, mining companies, and developers.

The mining industry will especially benefit from lower costs of electricity by approximately 30–50 percent, significantly improving the profitability and competitiveness of mining operations in Balochistan.

By investing in training initiatives, local communities can gain the necessary skills to actively participate in these industries, ensuring long-term sustainability and empowerment. Furthermore, local investments and operations should be encouraged in the rollout phase of the DPV. By leveraging the potential for local involvement, investment, and operation, the RE and mining sectors in Balochistan can create a positive impact on the local economy, job creation, and overall development. For details, please see Annex D: Financial and Economic Model.

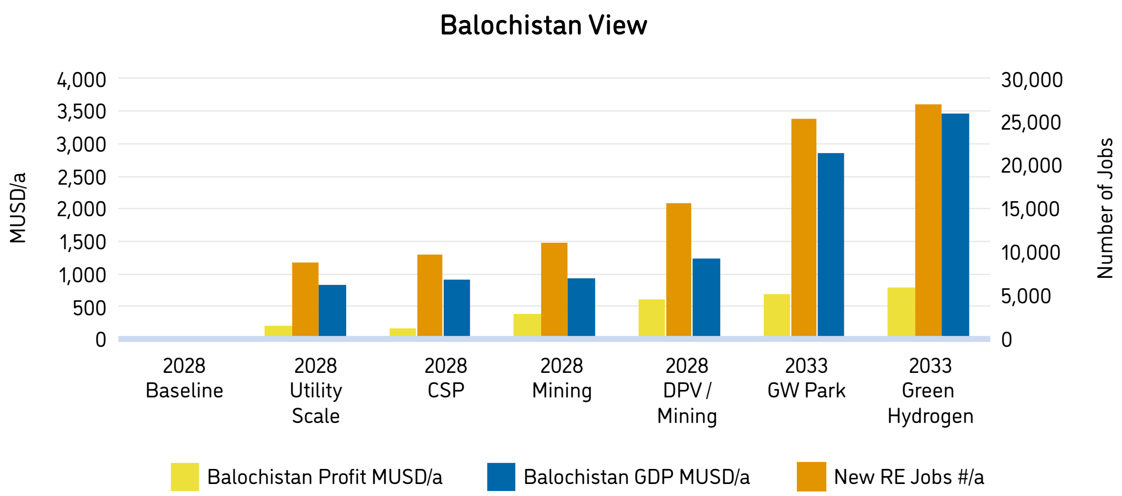
Figure 6.7: Economic impact on local industry by scenario – cumulative



Balochistan Perspective

The installation of up to 14 GW of VRE plants and an ammonia export facility can increase the GDP of Balochistan by approximately US$3 billion per year due to higher net export of electricity and more local income spent in the province. This would be a significant increase of US$8.3 billion in GDP in 2021.[55]

Figure 6.8: Economic impact on Province by scenario – cumulative



55 World Bank Pakistan Data, 2021

While the direct financial benefit to the province may not be in the form of direct revenue due to the prevailing burden of circular debt borne by the government of Pakistan, the installation of VRE plants in Balochistan can bring several indirect economic benefits, including job creation, reduced import dependency, potential electricity exports, and increased local income. These factors can contribute to improved living standards, economic growth, and regional development. Thus, the installation of 1.3 GW of VRE plants in Balochistan would lead to GDP growth of approximately US$0.5 billion per year.

National Electricity Supply Perspective

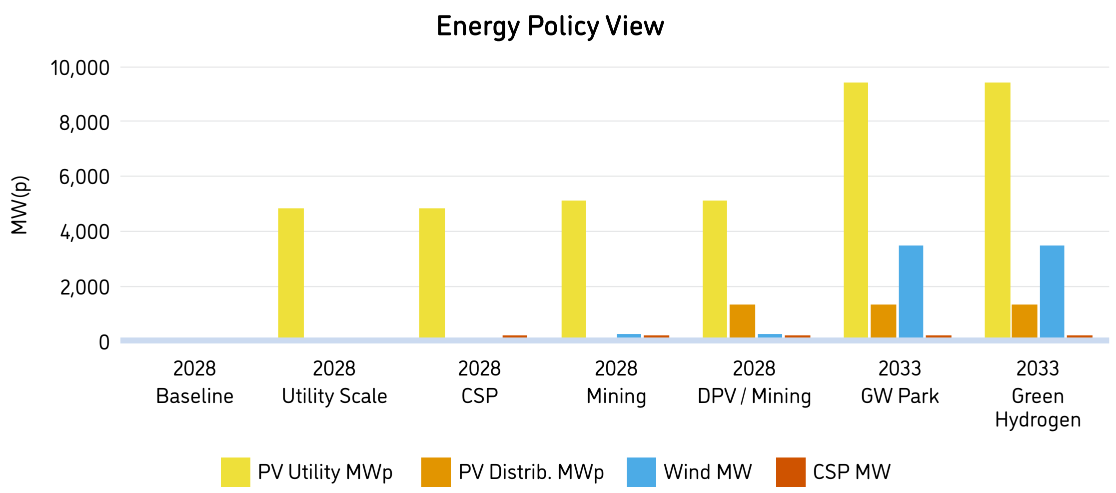
Balochistan currently faces challenges in maintaining a stable electricity grid due to factors such as load fluctuations, transmission losses, and inadequate infrastructure. Moreover, the cost recovery is low, leading to increased financial losses and circular debt within the sector.

By focusing on VRE implementation, specifically DPV systems, the MoE Power Division, NTDC, and CPPA can potentially address the challenges of grid stability, reduce circular debt, and leverage the cost advantages of VRE in Balochistan's electricity supply. This would contribute to a more sustainable and affordable energy sector in the region. In the "no VRE" base case scenario, the circular debt in Balochistan's electricity supply is projected to increase annually from 340 million as of today to US$492 million for the year 2028 simply by electricity cost inflation. However, implementing 75 percent of the potential of DPV systems would reduce this loss to US$105 million.

The constant production of electricity from various PV plants in the province can extend the lifetime of the gas supply from the Uch I and II plants. This is beneficial for the country as gas plants make a high penetration of VRE possible. Extending the lifetime of the lowest-cost gas plants in Pakistan would be an important step.

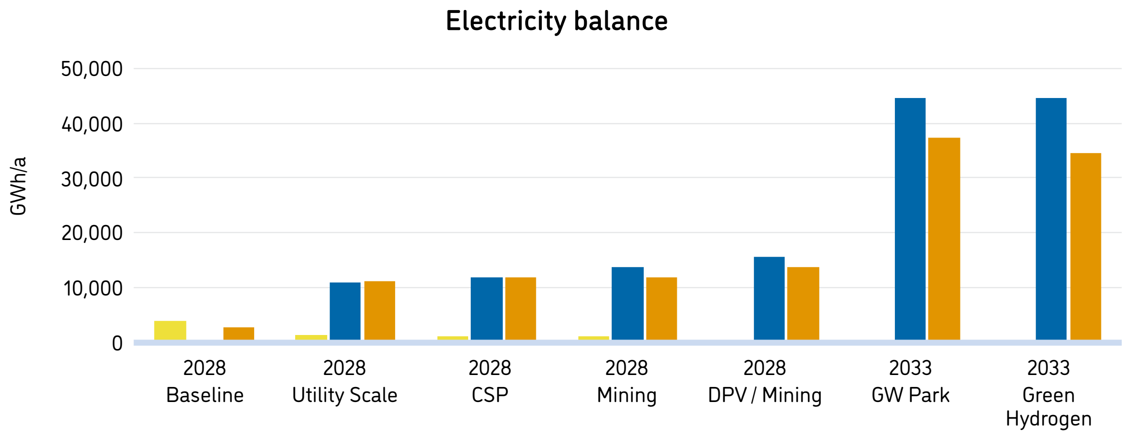
The VRE potential in Balochistan, being the lowest-cost option in Pakistan, presents an opportunity to leverage RE sources such as solar and wind power. With the better sites already planned to be connected through the utility-scale program up to 2028, further development of a GW-scale VRE park in Balochistan can offer a hedge against the availability risks associated with a larger portfolio of hydropower projects. This approach contributes to a diversified and reliable energy mix, reducing dependence on specific energy sources and enhancing the overall sustainability of the electricity supply.

Figure 6.9: VRE capacity development by scenario – cumulative



Today, Balochistan is a net importer of electricity—but it could soon become wholly electricity independent.

Figure 6.10: Electricity balance of province by scenario – cumulative

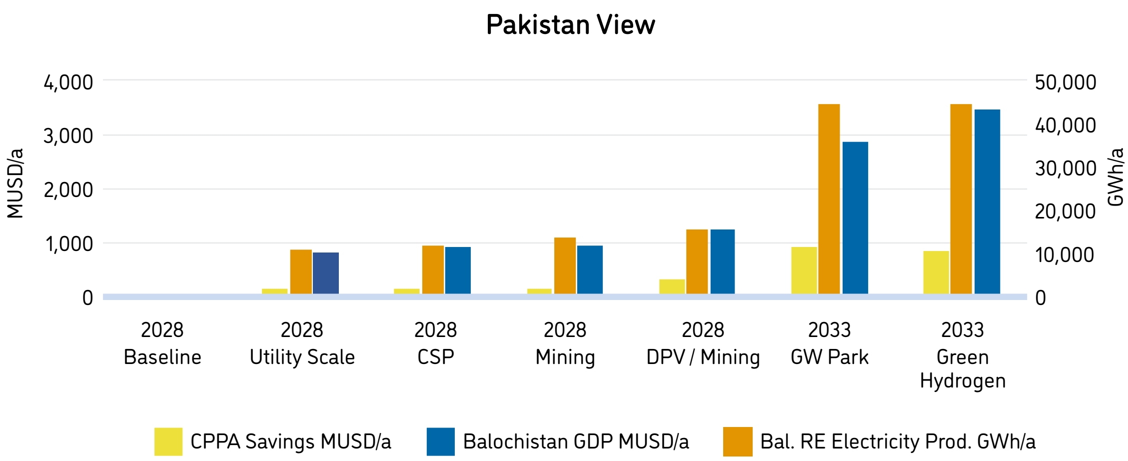


Pakistan perspective

The people of the other provinces will benefit from the cheapest supply of electricity and a reduction in circular debt. Any electricity provided using indigenous resources will reduce the need for imported fuel. This would also improve Pakistan's standing in the financial community, ending the anachronistic regime of subsidy to some 29,500 relatively wealthy farmers—a burden still borne by the entire country. Political leadership will benefit from an economic uplift in Balochistan and international recognition, especially from the IMF.

In the longer run, electricity from Balochistan will reduce the cost of electricity for other provinces by more than a US$1 billion and, in addition, electricity could be exported to Central Asia and even Iran and increase the foreign exchange reserves of the entire country.

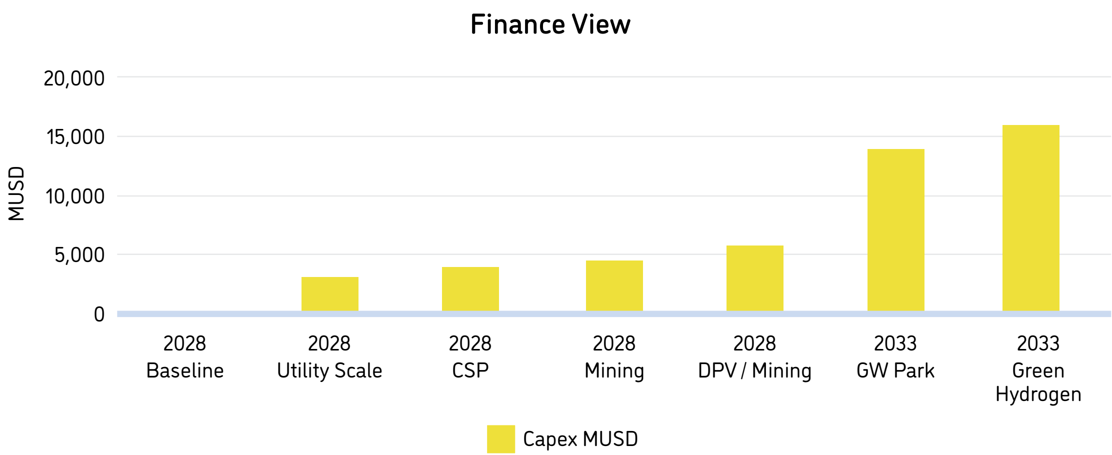
Figure 6.11: Pakistan view of province by scenario – cumulative



Financial market perspective

For the financial market, unlocking Balochistan's VRE potential would mean financing opportunities for more than US$14 billion.

Figure 6.12: Lender's view of province by scenario – cumulative



Given a secure off-take arrangement and security package, the financial market will take an interest in financing the projects on competitive terms. As the off-taker will be the CPPA, the same considerations will apply as for other VRE plants in other provinces. A beneficial approach would involve the province holding an equity stake to ensure long-term commitment and address potential challenges for each project's success and security. Development banks are likely to take the lead in financing the first few projects. Once a successful model has been established, commercial institutions may participate, potentially with support from the State Bank of Pakistan or development agencies through low-interest refinancing.

Global perspective

Globally all people will benefit from installations of VRE, reducing global CO_2 emissions. In addition, the creation of jobs will make Balochistan a less volatile part of the world, by starting to reduce the wide economic development gap between it and its counterparts that has afflicted it for so many decades.

Figure 6.13: Global view of GHG emissions reduction by scenario

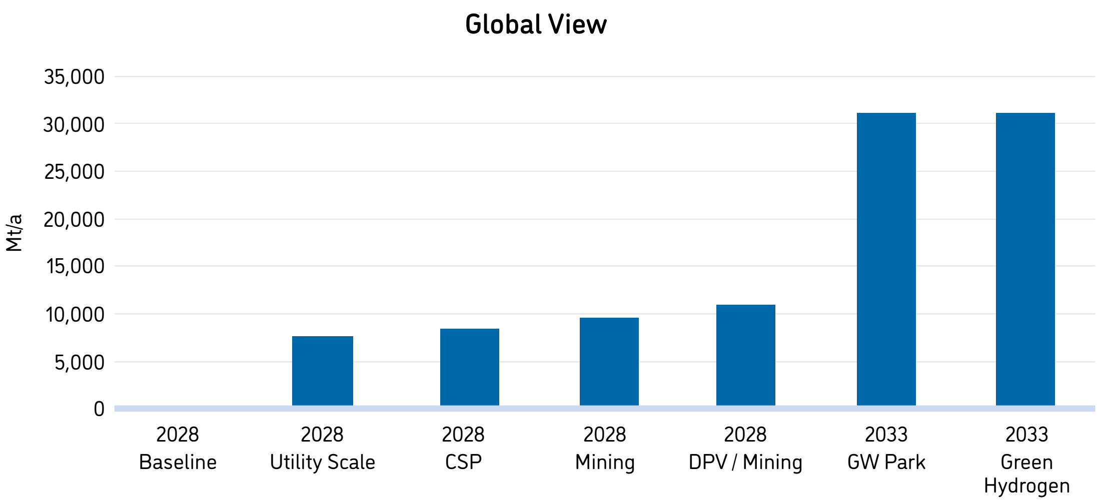


Table 6.4: Economic impact of options including distributed generation) summarizes key economic results for key parameters for the options evaluated. The figures are cumulative, any column is adding to the previous.

Table 6.4: Economic impact of options including distributed generation

Setting: Low demand	Unit	Zero VRE	Utility scale	CSP	Mining	DPV for farmers	GW park	Green hydrogen
Year		2028	2028	2028	2028	2028	2033	2033
Balochistan (Bal.) RE Electr. Prod.	GWh/a	0	10,942	11,978	13,646	15,701	44,522	44,522
Bal. Electricity Imp.	GWh/a	3,896	1,491	1,078	1,235	402	0	0
Bal. Electricity Exp.	GWh/a	2,850	11,177	11,800	11,869	13,845	37,446	34,459
Bal. Dev profit	US$, million/year	0	25	30	35	44	135	135
Bal. Industry profit	US$, million/year	0	0	0	138	138	342	393
Bal. Jobs income	US$, million/year	0	35	39	44	63	101	108
CPPA value	US$, million/year	0	149	152	161	338	936	839
Balochistan GDP	US$, million/year	0	833	918	942	1,239	2,860	3,469
New RE jobs	#/a	0	8,809	9,773	11,097	15,707	25,340	27,040
GHG reductions	Mt/a	0	7,660	8,385	9,552	10,991	31,165	31,165
CAPEX	US$, million	0	3,085	3,993	4,485	5,792	13,944	15,944
Economic NPV @ 12.5%	US$, million		2,544	2,337	3,982	6,824	11,821	n/a
Economic IRR (no IPPs)	%		24.7%	21.3%	25.6%	29.7%	25.1%	n/a
Economic Payback (no IPPs)	Years		4.0	4.6	3.9	3.3	3.9	n/a

The economic NPV assumes a 20-year lifetime of VRE opportunities. CPPA value includes the DPV benefits as those losses of today are with CPPA. It also assumes a cost advantage of US$ 2.5 cents per kWh for all exported VRE electricity from Balochistan (that is, US$ 5.5 cents per kWh compared to US$ 8 cents from other sources, maybe hydroelectric power).

The economic IRR would be immense as Pakistan would not invest in VRE but IPPs. For the case of Pakistan would invest, the IRR is calculated as well as the payback period.

The DPV case as a standalone case would have an NPV of US$2.8 billion and an IRR of 44 percent being the single most profitable option.

Please see 0Economic Assumptions for details.

7. Conclusion and Recommended Actions

7.1 Conclusion

Based on the analysis conducted under the VRE Locational Study (2021) and for this study, it is clear that the high solar resources in Balochistan make PV the most economical, quickest, and lowest-risk power generation technology in the province (with the addition of Chagai, where wind can play an important role). When sized optimally, PV in Balochistan can achieve line utilization factors up to 40 percent, and its supply profile correlates positively with the demand profile.

In cases where dispatchable power is required for evening and night load or for grid stabilization, CSP has a potential cost advantage. However, the uncertainty of expected cost made it very difficult to establish a solid baseline. Even active developers were not willing or able to share their assumptions. A combination of PV and BESS might be a cost-effective alternative unless the heat generated by the CSP process can be harnessed for additional purposes.

Utility-scale solar or wind plants connected to the existing grid present a clear opportunity to deploy up to 4.8 GW capacity almost immediately. PV and wind, possibly in combination with CSP or BESS and with fossil-fuel plants as a backup to supply electricity to the mining industry, are a very good opportunity for every mine in the province. Electricity costs can be reduced by about 30–70 percent compared to HFO, depending on the situation.

Additionally, DPV can contribute approximately 1.3 GWp and improve the power quality as line losses are significantly reduced.

A longer-term 7 GW park in Balochistan will be very beneficial for Pakistan as a whole, and for the region in particular. Any potential surplus can reduce the electricity import bill, especially from Central Asia. The relatively low-cost energy can be utilized to enable the export (and use) of green hydrogen.

For the implementation of identified opportunities, large corporations such as Engro Energy, Hubco, Pakistan Petroleum, and KE, which are already present in Balochistan, are ready to engage with the province and third-party technology providers to realize the potential.

7.2 Recommended Actions

7.2.1 Utility-Scale Opportunities:

The main bottlenecks for implementing any utility-scale VRE project are the lack of:

- clear targets and responsibility for developing projects,
- reasonable timeframe for allocating land for identified opportunities, and
- local development capacity.

Therefore, the followings are recommended:

National and Institutional Support

At a federal level, The PPIB and NTDC should support the opportunity to add the cleanest electricity to the national basket.

- For NTDC: Approving the plants identified in this study would be required. Grid interconnection readiness can be checked in-house.

For PPIB: The opportunity can be taken up for competitive bidding once the national competitive bidding process is finalized. To get the lowest cost with the highest line capacity factor, the bidding should focus on the maximum energy to be delivered into the grid (AC requirement) rather than a fixed DC size.

Project responsibility

A dedicated project management based in the province is needed to ensure provincial political support, especially for land allocation. Within Balochistan, it has been decided that BECL will be the province's focal point to facilitate the development of RE. To be able to perform, BECL would need to have clear objectives and additional funds to mobilize required resources to meet this expectation. Objectives for BECL could be:

- Identify MW of opportunities prepared and ready for tendering.
- Offer clear services to developers regarding:
  - equity for land;
  - standard contracts preferably on BOOT concept (build, own, operate & transfer) so that the plants become wholly owned by BECL after 25 years;
  - infrastructure development support based on local knowledge and experience;
  - security offer based on local knowledge and experience;
  - definition of a standard corporate social responsibility requirement; and
  - support the regulatory and grid connection process.
- Actively seek and select developers to team up with.

The resources required for successful implementation are:

- Dedicated and knowledgeable project management capacity with a developer mindset (and compensated accordingly);
- Interdepartmental support to deliver on the objectives; and
- Some budget for travel and necessary studies to finish prefeasibility and interconnection studies for all the identified sites once the land is allocated.

Furthermore, as soon as installation activity is in progress in the province the aspect of local manufacturing, for supporting structures, for example, should be explored.

Political Support

The BECL would need support and backing from the highest level in the province:

- The province needs to back up the BECL's mandate wholeheartedly;
- All project opportunities would require earmarked land (this has been lacking in the past);
- Local employment should be encouraged through a quota system. Compensation rules should be developed, and security guarantees are given;
- Key discussions and agreements with the MoE's Power Division and other federal institutions need to be held regularly; and
- A monthly review process should be implemented to identify gaps and monitor progress.

7.2.2 Mining

- As the requirements and advantages of VRE vary for each individual mine, it is recommended that each mine operator independently conduct a feasibility study and collaborate with developers to implement the necessary measures for achieving savings.

- If a grid expansion is beneficial, and the mining operator is ready to finance its cost, QESCO should be willing to implement it. In addition, QESCO would gain customers and could purchase any surplus energy from the mine at a low cost. The BECL and Department of Mining could promote the use of VRE and distribute the attached sample prefeasibility studies to serve as the baseline.
- Realization of a pilot project at the Reko Diq site could be a tremendous marketing opportunity and should be facilitated at the highest level in the province. Pakistan Petroleum is a shareholder of the Reko Diq project and would be ready to get engaged.

7.2.3 DPV

Three interventions are suggested to move forward with a DPV program:

- Dedicated impetus from the provincial leadership to address the problem;
- Provincial project management for implementation; and
- Maximum support from the MoE Power Division.

Key Decisions Needed

The provincial leadership would need to decide to tackle the problem and mandate the Energy Secretary to develop a pilot model for implementation as a first step:

- The province will need to select some pilot feeders;
- The province needs to establish a project manager with clear objectives backed by senior leaders of the province;
- The province would need to identify interested financial institutions to fund the pilot projects;
- Key discussions and agreements with the MoE Power Division and other federal institutions would need to be followed up regularly; and
- A monthly review process would need to be implemented to identify needed support and progress.

Project Responsibility

A special-purpose vehicle or a departmental project management unit for implementing the pilot projects and formulating a rollout strategy would need to be created. This project management unit will be mandated with clear objectives and provided adequate resources to perform. Objectives should be:

- Preparing initial documentation on feeder selection and farmers' consent and request for funds;
- A clear structure on how to implement pilots based on already conducted feasibility study; and
- Teaming up with selected developers.

Resources needed are:

- The manpower to follow up, which is already in place and only needs to be channelized;
- Interdepartmental coordination and support to deliver on the objectives; and
- Budget for travel and studies to facilitate pilot financing processes.

National support

The MoE's Power Division should request and support the government of Balochistan to develop a structure that ends the subsidy regime. The role of QESCO as a national entity should be reduced to supply power to the 132 kV grid stations and provide maintenance service on the 11 kV feeders only. Billing should be done in bulk for the annual net feeder consumption to an independent feeder operator responsible for maintaining the DPV and power management on the line. This is in accordance with proposed federal initiatives that promote DPV on 11 kV lines and contract out billing on feeders (MoE power division, 2022).

At present, only two items need to be implemented: the potential cost and output of the park should be evaluated in the longer-term planning (IGCEP) on a regular basis; and a comprehensive feasibility study on park development should be initiated.

Once the overall decision for establishing a VRE GW park is taken, a park management facility within the BECL or another entity can be set up to structure park development according to electricity demand forecast and tender out parts over time to IPPs.

7.2.4 GW Opportunity

The GW opportunity should be led federally once a high-level agreement to follow up on the opportunity has been made. The provincial leadership and BECL can support and push on the local level.

Indicative Generation Capacity Expansion Plan: The different development phases of the GW park should be modeled for the IGCEP to understand the overall evaluation in the long-term national concept. This should include the export option for the CASA line and eventually Iran as well.

Masterplan development: A comprehensive masterplan / feasibility study to determine location, bankable wind resources, and stagewise grid connections cost would be essential to support the assumptions made in this study.

- Wind resource is only available for Chagai which is in private hands. For other potential locations in Panjgur and Turbat suitable areas for wind power should be identified and wind speed measurements should be taken;
- A strategy to connect the site to the national grid to reduce high grid connection cost in the initial growth phase of about 2–5 years of the project should be established;
- Cost and employment assumptions as well as provision of housing and other infrastructure for GW-scale park need to be verified in more detail;
- Park management and provision of provincial services to facilitate developers and financing institutions should be ensured; and
- Either the government of Balochistan or PPIB should take the lead in initiating such a master plan.

7.2.5 Export

Exporting electricity via existing lines to Central Asia and Iran should become a national target. Especially in the case of Central Asia, there should be an excellent case for a seasonal exchange of electricity. It is noteworthy that countries in central Asia might be interested in supporting the GW opportunity for their electricity demand in winter. Therefore,

- CPPA should take up the discussion with relevant counterparts in Central Asia and Iran.

Countries in central Asia might be interested in supporting the GW opportunity for their electricity demand in **winter.**

7.2.6 Green Hydrogen / Ammonia

Green hydrogen/ammonia could likely be produced at competitive terms given the low cost of RE in the province. There are a number of larger local corporations, such as Engro Energy, Hubco, and Pakistan Petroleum, which should be mobilized to reach out to international technology providers to explore the opportunities in detail. A large green hydrogen or ammonia facility would be mainly for export and should be taken up federally. The MoE has already expressed its interest in such a motion, and the BED offers its support. There are a number of larger local corporations, such as Engro Energy, Hubco, and Pakistan Petroleum, which should be mobilized to reach out to international technology providers to explore the opportunities in detail.

Preliminary steps include a detailed feasibility study if the governments of Pakistan and Balochistan want to go ahead with the project. For successful market entry, bilateral linkage with import markets will likely be required on a political level (such as the EU and Germany) to ensure financing as well as guaranteed off-take of green hydrogen/ammonia. Therefore establish a strategic partnership (such as between BMZ Germany and the government of Pakistan) to conduct a feasibility study, then set up a pilot plant, and then scale up.

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Annex A: Concentrated Solar Power Technology

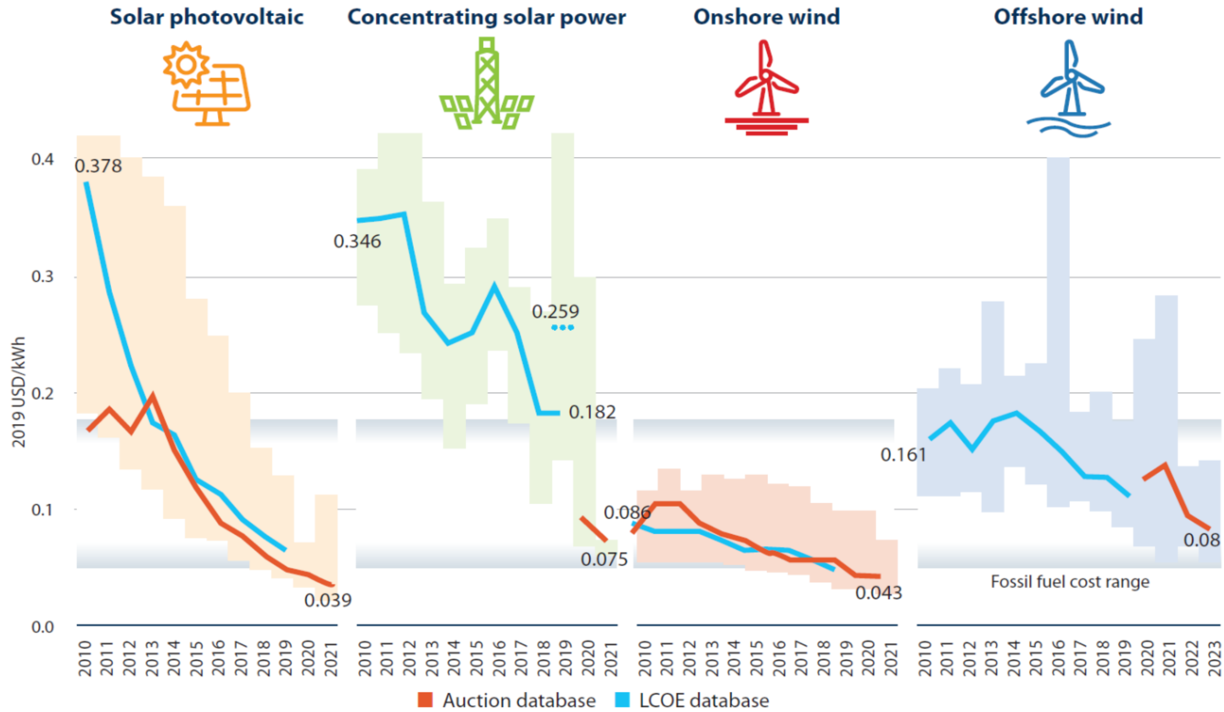
A.1 CSP Technology Cost

CSP as a technology for power generation has existed for many decades now, with the first wave toward commercialization in 2010 and further renewed interest in recent years as a source of baseload power for countries with high solar irradiation (for example, Morocco, Saudi Arabia, and Chile). Up to now, the global CSP market has been relatively small with around 6 GW of installed power, compared to PV technology which has installed power of 600 MW.

CSP technology comes in different setups as described in the section 2.3.4 and involves a number of different specialized components. As a result, the CSP market today is much less developed and standardized compared to other RE technologies. This means that the numbers available on technology costs in commercial plants are limited and therefore have a much higher variation and uncertainty compared to more established technologies.

The World Bank, together with IRENA, recently published a report called "Concentrated Solar Power – Clean Power on Demand 24/7" (World Bank, 2021), bringing together recent market information and insights on CSP costs and technology. The following chart is taken from this analysis. The blue lines show the calculated LCOE of worldwide projects, based on data available from IRENA internally, while the red lines show the results of PPAs that have been made public.

Figure A.1: Development of cost levels for different RE technologies



Source: IRENA (2020).[56]

56 The thick lines are the global weighted average LCOE or auction values by year. The grey bands, which vary by year, are the cost/price range for the 5th and 95th percentiles of projects. For the LCOE data, real weighted average cost of capital is 7.5 percent for China and members of the OECD and 10 percent for the rest of the world. The gray band that crosses the entire chart represents the fossil fuel fired power generation cost range. CSP: concentrated solar power; LCOE: levelized cost of electricity; PPA: power purchase agreement. The prices are quoted in nominal terms.

The chart shows clearly:

- **CSP is the most expensive RE technology** on a per-unit basis (LCOE) among the four technologies shown. This cost difference is much less for the public PPA prices (red line). However, for CSP this data derives from a couple of sites under very specific conditions (for example, excellent solar resources, very large plant sizes of several hundred megawatts, and very favorable financing conditions as in Dubai (Noor I), which was the reference for the US$0.075/kWh). For the "LCOE database" (blue line), CSP costs are more than double (US$0.182/kWh).
- **The uncertainty in LCOE numbers** (represented by wide ranges of light colored bars in the background) **is quite high for CSP**, reflecting the still nascent market and comparatively low number of projects worldwide under very different conditions, leading to higher variation in costs.

Important findings from the same report are:

- The chart shows a high difference in LCOE between "IRENA LCOE database" (currently at **US$0.182/kWh)** and "IRENA auction database" (based on the Noor 1 park in Dubai, located in the same region, about 1,500 km away from the sites in question, which has achieved a tariff of only US$0.073/kWh for CSP albeit on excellent financial conditions and at a 35-year PPA which is above the standard 20–25 year term).
- **CSP as base load**: The average capacity factor (that is, the ratio of operational hours and total hours of the year) of CSP plants worldwide increased to 45 percent in 2019 (compared to below 20 percent for PV, for example). A capacity factor for CSP is 45 percent, which seems low when compared to fossil-fuel thermal plants with 90 percent and above, but higher than for PV or wind technology. The capacity factor for CSP is further increasing for the new plants being built.
- **Typical storage hours** in the past were 3–8 hours, while the average of the eight plants mentioned in the report as "under construction" is almost 12 hours, indicating a strong trend toward higher storage and longer daily operation.

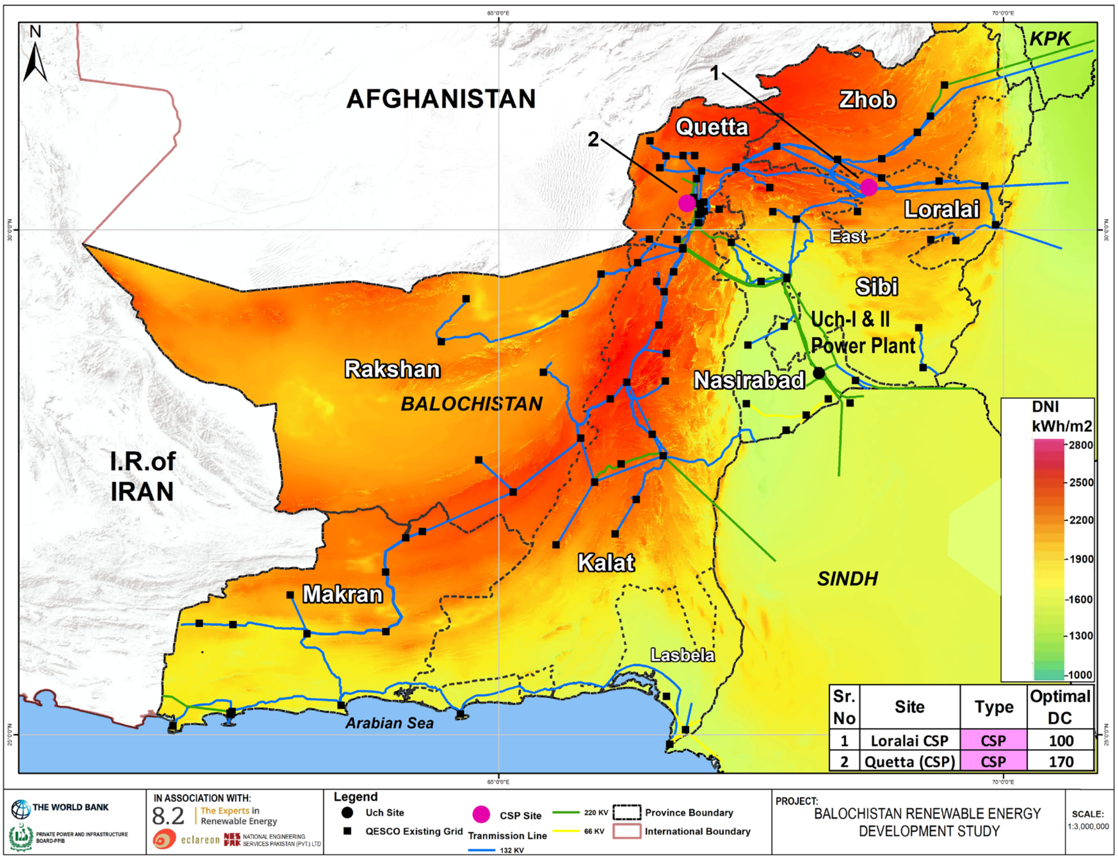
Due to their experience and the global reach of World Bank and IRENA, the numbers quoted in this report can be assumed as a safe baseline for this analysis.

A.2 Site Selection

Local conditions play an important role for all kinds of energy technology; this is acutely applicable to RE and specifically for CSP. As mentioned earlier, solar irradiation in Balochistan as a whole is quite high (that is, GHI for PV: around 2,200 kWh/m^2 p.a.).[57] DNI as the relevant resource for CSP technology is excellent with values of up to 2,500 kWh/m^2 per year. CSP projects have been implemented at DNI levels of 2,000 kWh/m^2 (such as Dubai), so 2,500 can be considered as an excellent irradiation level.

57 Global Solar Atlas

Figure A.2: DNI in Balochistan



Source: Global Solar Atlas

A concern for CSP development is the higher uncertainty of DNI data compared to GHI. DNI, contrary to GHI, only considers the irradiation coming directly from the sun and therefore depends on a clear sky. This means that satellite-derived DNI data (as used for the above figure) is much less reliable than ground-measured data. Hence, it is standard industry practice to measure local DNI data for at least one year through a specialized weather station on the ground before designing a CSP plant for that location. Such local ground measurement would be required prior to opening a CSP tender.

A.3 Environmental Impact of CSP

Like any other energy plant or large infrastructure project, CSP plants have certain impacts on the environment. However, the impact of a CSP plant on climate in terms of GHG emissions is minuscule compared to fossil fuels, and their impact on air and water is in no way comparable to those of coal plants. However, the following impacts that do exist should be considered.

Water usage: CSP plants mostly run on thermal steam turbine cycles, which means that they need a continuous re-cooling of the turbine cycle, which is most efficiently done through wet cooling. However, where freshwater is scarce (as is the case in Balochistan and most areas where CSP plants are built), dry cooling is the better option, albeit coming at some cost to plant efficiency.

From the CSP Water Study (US Department of Energy, 2007), the following can be derived (and similar values are found elsewhere in the literature): CSP parabolic trough technology has about 500–800 gallons (2,300–3,500 liters) of water usage per MWh for wet (recirculation) cooling, while this reduces to 10 percent (about 350 l per MWh) for dry cooling (at a certain performance and cost penalty).

Land use and visual impact: Every infrastructure installation has a certain land use and corresponding visual impact. The land usage for a CSP plant is larger, per MWh, than that for wind and fossil fuels, but comparable to or less than that for PV. However, this aspect is of little relevance for Balochistan where lots of empty land is available in the areas in question.

Energy and materials usage: Life-cycle assessments of CSP power show that the cumulative primary energy invested in the construction and operation of a plant over its lifetime is gained back as generated renewable power in less than one year, whereas a CSP plant can last for 30 years or more. This gives an energy return on investment of about 30, which is excellent.

In terms of construction materials, the requirements for CSP are much higher than for coal or gas, which is understandable, given that the material-intensive solar collector field of CSP is a completely additional component compared to fossil fuel plants. However, the materials used for CSP are mostly concrete, steel, and glass, thus posing no environmental hazard.

Emissions: GHG emissions of CSP plants are evidently much lower than for fossil fuels, and stem mostly from the life-cycle analysis (construction and maintenance). Additionally, there are some minor emissions such as nitrous oxide (evident in lifecycle analysis of salt storage) which are again negligible compared to fossil plants.

Flora and fauna: Similar to other power plants, CSP plants can theoretically interfere with the migration of birds or other animals; however, this is a rare and rather negligible effect. Direct damage to birds (such as burning through concentrated sunlight) seldom happens and is definitely less than bird or bat damage through wind power plants, for example.

Overall, the most important impacts of CSP plants for Balochistan are its water usage as well as its material consumption (as well as required logistics infrastructure development) for construction.

Annex B: Socioeconomic Impact

B.1 Overview

Regarding the socioeconomic impacts the following aspects were assessed:

- Impact on job creation
- Impact of increased employment on Balochistan's GDP
- Impact of decreased imports / increased exports on Balochistan's GDP
- Local participation examples

The impact on job creation was assessed following the (World Bank, 2022) methodology. The newly created jobs (direct and indirect) in onshore wind and solar PV (grid scale) were estimated in three development phases (development & preconstruction; construction; and operation & maintenance).

The impact of increased employment on GDP aims to measure the income effect on GDP caused by the newly created jobs (permanent). To this end, the multiplier estimated by (Shaikh, Shah, & Shah, 2015) will be employed. Accordingly, the effect on local and regional GDP caused by the number of newly created jobs and consequently the average yearly wage is estimated.

The impact of new RE investments on GDP is based on the estimation of the gross value added of the RE investment, which is mainly the difference between total revenues and intermediate consumption. The methodology is primarily based on (UN, 2019), and (EWEA, 2012). On the one hand, total revenues are calculated based on the price of electricity generated by the plant and the amount of electricity produced by the plant over a given period of time. On the other hand, intermediate consumption is the cost of each item used in the production process. More specifically, intermediate consumption includes the OPEX of the RE plant, while part of the CAPEX is also included.

B.2. Impact on Job Creation

Beyond the preliminary calculation regarding RE deployment in the Balochistan region, it would be important to underline the socioeconomic impact of RE uptake. For that reason, the impact of job creation will be described. The calculations included in the file are based on the methodology provided by the (World Bank, 2022).

World Bank (2022) described a comprehensive methodology to assess the expected job creation triggered by two specific policies: the ambitious national RE targets under a new RE policy announced in 2020 and the Integrated Generation Capacity Expansion Plan 2021–2030 (IGCEP 2021–2030) prepared by the NTDC.

This study adopted the methodology. The first step is to look into the renewable energy employment factors provided by the World Bank in order to calculate the direct jobs created due to RE development.

Table B.1: Renewable Energy Employment Factors[58]

	Development and preconstruction FTE Jobs/MW	Skilled (%)	Semiskilled/ Unskilled (%)	Construction FTE Jobs/MW	Skilled (%)	Semiskilled/ Unskilled (%)	(O&M) FTE Jobs/MW	Skilled (%)	Semiskilled/ Unskilled (%)
Wind (onshore)	1.2	14	86	2.5	83	17	17	15	85
Solar PV (utility-scale)	0.2	100		5.5	6	94	0.8	29	71

Source: (World Bank, 2022)

58 An FTE is a unit to measure employment in a way that makes it comparable across employees and industries.
For example, a job that can be completed by one person in 24 weeks represents 0.5 FTE job-years when the entire work year includes 48 weeks. Conversely, a job that requires 96 weeks to complete and has to be finished within a year represents at least 2 FTE job-y

This study used the employment factors of wind (onshore) and solar PV (utility-scale).

For the GW scale, 50 percent of the O&M resources were assumed because high economies of scale can be expected.

The DPV job factor is assumed to be 50 percent higher than in the utility-scale category. Development and preconstruction are not considered.

Wind construction time is two years and PV construction time is one year and this will also be adopted in the report. The results will be expressed in full-time equivalent job years per GW. To smooth the impact of construction time spikes, the construction-induced jobs are divided over a 20-year plant lifetime.

Apart from the direct impact on job creation, the indirect impact will be estimated. Indirect jobs are defined as employment in companies providing inputs to the RE development, such as jobs created in the steel sector (World Bank, 2022). Indirect jobs are estimated as 70 percent of direct jobs (Rutovitz & Harris, 2012).

As mentioned above, the distinction between temporary and permanent jobs is:

- Temporary: development and preconstruction and construction
- Permanent: O&M

The distinctions between skilled & semiskilled/unskilled were based on NRDC and CEEW (CEEW & NRDC, 2014b; CEEW & NRDC, 2014a) and (World Bank, 2022). Skilled workers are defined as individuals who hold a degree or technical diploma qualification, while semiskilled/unskilled workers have vocational qualifications or on-the-job training in low to moderate skills (World Bank, 2022). More specifically, for PV, the estimations of (CEEW & NRDC, 2014b) for PV plants above 25 MW were adopted.

B.3 Impact of increased employment on GDP

GDP is defined as the value of the total number of goods and services produced inside a country in a given period of time. This relationship can be shown through the following equation (Mankiw, 2020) :

$$GDP = C + I + G + NX \quad (1)$$

Where,

C = Consumption

I = Investment

G = Government spending

NX = Net exports (exports – imports)

Here, consumption is the sum of expenditures by households on all goods (durable goods, nondurable goods) and services. Investment is the sum total of all private expenditures on capital equipment, tools, inventories, and structures. Government expenditure is the sum total of expenditures on purchases of goods and services by the public sector. Net export is the difference between the earnings from exports minus payment for imports.

As part of GDP, this part will focus on consumption and more specifically household final consumption (the sum of expenditures by households). The main aim is to show how the income generated by the newly created installations can have an impact on local and regional GDP.

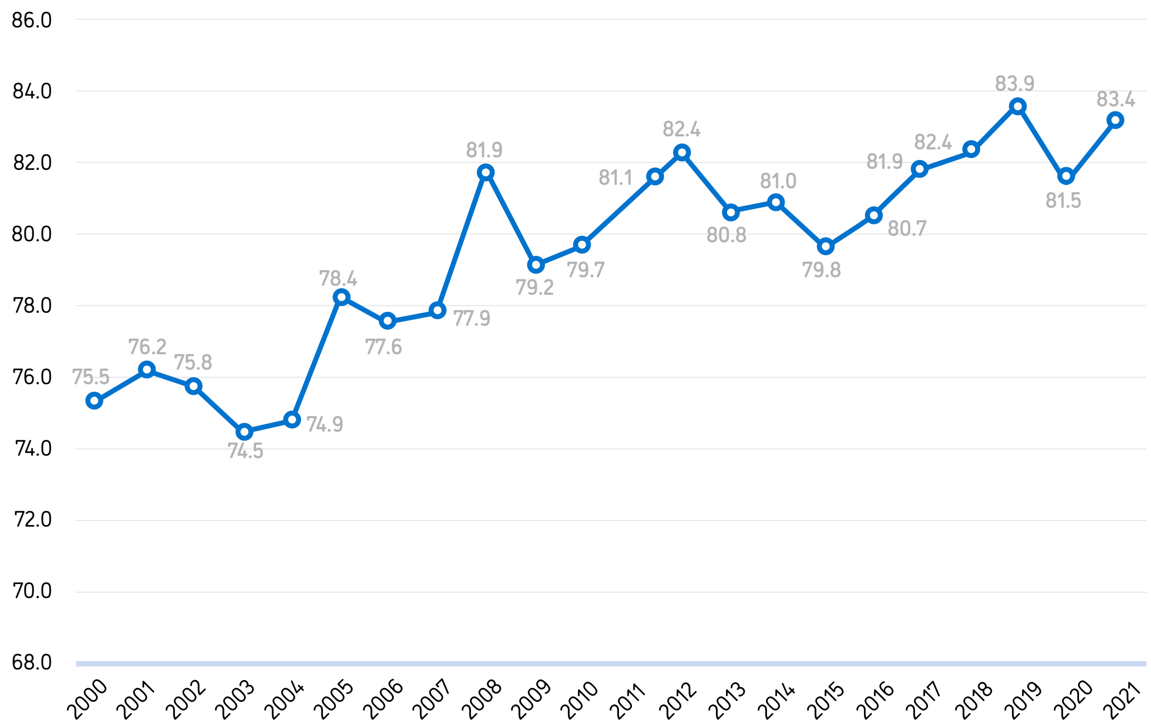
Figure B.1 shows clearly that household final consumption is always a substantial part of GDP. Based on that, Shaikh, Shah, & Shah (2015) estimated the marginal propensity to consume (MPC) in Pakistan for the period 1985–2011. MPC is defined as the rate of change in consumption due to the one-unit change in income. The estimation of MPC was the first step to calculating the multiplier, which is the following (Dorbusch & Fischer, 2017):

Multiplier= 1/ 1- MPC

The multiplier estimates the changes in the GDP as the consumption changes by one unit (Shaikh, Shah, & Shah, 2015).

The multiplier will be used to assess the effect of increased income in the local and regional economy in Balochistan. The rationale is that RE deployment in the region will lead to new jobs and therefore to increased income. This new income will be spent primarily in the local and regional economy (as the MPC shows). However, this new income will have multiple effects as a chain reaction of the increased consumption due to newly generated income on the local and regional economy and to GDP. The multiplier aims to assess the aggregate effect of the increased income due to new jobs on the local and regional economy and to GDP.

Figure B.1: Household consumption in Pakistan (% of GDP) during the period 2000–2021.



Source: World Bank Online Data/ Pakistan

One main assumption for the calculation of the aggregate and sustainable impact on GDP due to new jobs is that only permanent jobs will be assessed. The permanent residents are expected to consume their income within the region of Balochistan. In contrast, temporary workers may come from other regions of Pakistan and, therefore, their salary will be expected to be consumed not only in Balochistan but also in other regions. Additionally, temporary workers are not expected to stay in Balochistan once their work contract is terminated, so the impact on regional GDP will be temporary. Further assumptions are presented in Table B.25.

Table B.2: Assumptions on the estimation of GDP impact by new jobs

Assumptions		Source	This study PKR/y	Reason
Minimum monthly wage for unskilled workers in Balochistan	PKR 25,000	Paycheck.pk, Minimum wage - Balochistan	80,000	Inflation
Monthly wage for skilled workers in Balochistan (median salary)	PKR 70,400	Salaryexplorer.com, Average Salary in Pakistan	120,000	Inflation
MPC	0.821	(Shaikh, Shah, & Shah, 2015)		
Multiplier	5.587	(Shaikh, Shah, & Shah, 2015)		

The calculation equation is the following:

GDP Impact= [(Wunskilled * Nunskilled)+ (Wskilled * Nskilled)]* Multiplier (2)

Where,

$W^{unskilled}$= Yearly wage of unskilled worker

$N^{unskilled}$= Total number of new unskilled workers

$W^{skilled}$= Yearly wage of skilled worker

$N^{skilled}$= Total number of new skilled workers

Multiplier= 5.587

Based on the equation, a primary assessment of the contribution of newly created jobs due to increased VRE plant installation and operations on GDP was used.

B.4 Local Participation

The following examples show how local participation and categories of incentives can be combined.

The first example is from Greece. This hybrid approach aims at combining all three categories of incentives. More specifically, there is a special tax to increase the acceptance of RE projects by local communities and municipalities. The special tax of 3 percent is deducted every year from the revenues of RE developers and remitted to local administrations. According to the latest framework,[59] the special tax is currently divided as follows:

- Up to 40 percent goes from the Greek Electricity Market Regulator to the electricity suppliers of the area where the RE is located. They are obliged to pass the above amount on to household consumers through their electricity bills, that is, the reduction of the household consumers' electricity bills; and
- The rest is offered to municipalities for environmental actions, local development, and social support projects.

The special tax combines the incentive of the discounted electricity tariff with payments to the local administration. In addition, the tax revenues should be directed to social purposes.

The second example is from the UK and more specifically from Scotland. Here, the Community Benefit Fund is foreseen for each onshore wind project. It entails a voluntary scheme for onshore wind. However, all RE developers are establishing it to increase public acceptance. The funding suggestion is £5,000 per installed MW per year, and the funds should support the realization of social projects in the area where the onshore wind plant is located. The RE development is in charge of setting up the fund but a community panel comprised of local residents decides on the projects. The Community Benefit Fund has been established as a standard procedure that contributes to community engagement in Scotland (Scottish government, 2019).

Apart from the above-mentioned examples, which are focusing on the distribution of funds to the local community, there are also other possible options to enhance local acceptance that can be combined with the previous local acceptance measures. For example, local job creation and service delivery can be seen as of primary importance for some local communities. Ensuring local employment and local procurement can stimulate local economic development and improve living standards. In parallel, this commitment by the RE developer can increase public acceptance of the RE development. With the involvement of the local community, the RE developer can establish local procurement policies, train local suppliers, discuss the development of education opportunities for skill development, and train local staff for O&M. In any case, this option will require time, because it is a process that needs to be communicated to the local community and the local community needs time to adapt and make the most of the opportunities (Lane & Hicks, 2017).

One example of local job creation is that of the Moree Solar Farm, New South Wales in Australia. The RE developer introduced a community consultation plan and in cooperation with further engagement activities, three-quarters of the 150 construction jobs created were awarded to local workers, while five workers are permanently working on O&M. Additionally, the RE developer established a benefit-sharing program similar to the Community Benefit Fund (Lane & Hicks, 2017). This shows once more that all local acceptance measures can be combined for the optimal outcome.

All three examples show that there are many potential options to increase local acceptance. The key issue is ensuring that the local community feels that it is part of the RE development. This can be facilitated by establishing the local community's early engagement and keeping communication channels open. In addition, there are a number of specific measures that should be tailored to the local context and would therefore successfully increase the local acceptance of RE development in Balochistan.

59 Law No. 4652/2022.

Annex C: Hydrogen Model

HySupply is a collaboration between Germany and Australia to investigate the feasibility of exporting RE in the form of hydrogen from Australia to Germany and identify how this partnership can be facilitated. For Australia, the consortium is led by UNSW Sydney and is funded by the Department of Foreign Affairs and Trade and the Department of Industry, Science, Energy and Resources[60].

As part of the feasibility study, HySupply Australia is developing a series of open-source and open-access costing tools to assess the viability of this supply chain. These open-source tools will be released as an asset of the HySupply project with the intent to iteratively improve existing functionalities and data sets to provide holistic, high-level, prefeasibility assessments for possible hydrogen projects, as they build toward a complete value chain assessment tool.

The HySupply Ammonia Analysis Tool is being released for further consultation with stakeholders to facilitate discussion regarding the development of an Australia-Germany green hydrogen/ green ammonia supply chain.

Table C.1: Inputs for HySupply

Target output of green NH3 per year	1 Mt per year
Ratio between wind and PV for generation (for example, 50:50)	50: 50
Balancing technology for NH_3 synthesis	Grid
Storage size H_2	500 t (approx. 14 hours)
Oversizing of VRE plants against electrolyzer	140%
Oversizing of electrolyzer against ammonia plant	120%
Cost PV (1-axis tracked) (CAPEX/OPEX)	US$680/kWp / US$10/kWp p.a.
Annual capacity factor PV (1-axis tracked)	26.4%
Cost wind (CAPEX/OPEX)	US$1,180/kWp / US$20/kWp p.a.
Annual capacity factor wind	44.5%
Cost of electrolyzer (CAPEX/OPEX)	US$1,675/kW / 2.5% of CAPEX p.a.
Cost of ammonia synthesis (Haber-Bosch) (CAPEX/OPEX)	US$536/tNH3 p.a. / US$670/tNH3

Table C.2: Outputs of HySupply

Levelized costs of H_2, NH_3 (LCOH, LCO-NH_3)	See charts in chapter
CAPEX breakdown, LCOH/NH_3 breakdown	See charts in chapter
Electrolyzer capacity factor of whole year	82%
Ammonia plant capacity factor of whole year	100%

60 More details can be found at Globh2e Website

Annex D: Financial and Economic Model

D.1 Project Opportunity Evaluation Model

The quantitative analysis for this report is based on a cash flow model using electricity volumes and expected cost for each opportunity in every scenario (low and expected load forecast by 2028 and 2033). The total cost of each scenario is compared to the base case (no VRE in Balochistan). The origin of the model was developed by the 8.2 group in 2010 and adapted for various countries. It is based on hourly load assumptions and energy production simulations over one complete example year (8,760 hours). For every hour, input parameters for a specific area (load) or site (supply) are determined.

The load assumptions used are from QESCO and distributed over the days. Basic data for grid analysis was obtained from NTDC and QESCO.

The VRE supply assumptions such as ambient temperature, solar power output, wind power output, and so forth were taken from the Global Solar Atlas and the Global Wind Atlas[61] and modified by ground measurements for the Chagai area. Based on these parameters, secondary values are calculated, such as net generation and expected electricity cost by project opportunity (26 utility-scale power plants at a specific location). This tool has been used to calculate technical and financial results for the whole year including capacity factor, generation pattern, and expected PPA of the plants for CPPA/government of Pakistan on the country level. The same tool has been used in the VRE Locational Study Pakistan (World Bank, 2021).

The PV plants are assumed to be on one-axis trackers as that technology offers the lowest expected cost of electricity in Pakistan for utility-scale PV plants. The PV plants were sized to maximize grid evacuation capacity at minimal curtailment. This was an average factor of grid evacuation capacity in AC MW x 1.3 = DC MWp nameplate of the plant.

The DPV production was performed for 23 sites in detail and scaled to size the estimated regional agriculture load. The identified energy efficiency measures of efficient motors/pumps and reduced line losses were included. The CAPEX and OPEX assumption also includes the energy efficiency cost.

It is assumed that Pakistan will be able to monetize 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 additional benefit.

D.2 Financial assumptions

The financial model for all project opportunities assumes a PPA contract between the developer and CPPA according to competitive bidding guidelines (World Bank, 2022).

In the financial model the expected CAPEX and OPEX for every site has been estimated. It is assumed that the developer would strive for an 18 percent return on investment for 25 percent equity. The remaining 75 percent debt would be provided for 15 years (80 percent at 8 percent interest from international sources and 20 percent of the debt would be provided locally at 20 percent interest). In an alternative case, the debt was provided at six percent interest. This might be valid for preferential loans from development banks or in government-to-government mode. The model is in US dollars assuming a fixed PKR/US$ exchange rate of 300 with four percent annual inflation.

D.3 CAPEX and OPEX assumptions

All VRE plants are simulated using the same cost assumptions considering economies of scale for larger plants.

61 Global Wind Atlas and Global Solar Atlas

Table D.1: Category cost assumptions for PV

Category	Unit	Value
Modules	US$/Wp	0.20
Inverter	US$/Wp	0.03
Tracker	US$/Wp	0.09
Installation	US$/Wp	0.11
Civil	US$/Wp	0.04
Transformer	US$/Wp	0.08
Land	US$/Wp	0.02
PM & EPC	US$/Wp	0.10
Total	US$/Wp	0.67
CAPEX Fix	%	15
CAPEX dependent on size	%	85
OPEX – annual	US$/Wp/a	0.01

Table D.2: System size CAPEX assumptions for PV

System size	Unit	Value
50 MWp	US$/Wp	0.77
100 MWp	US$/Wp	0.67
150 MWp	US$/Wp	0.64
200 MWp	US$/Wp	0.62
300 MWp	US$/Wp	0.60
500 MWp	US$/Wp	0.59
1000 MWp	US$/Wp	0.58

Table D.3: Category cost assumptions for Wind

Category	Unit	Value
WTG	US$/W	0.90
Converter	US$/W	0.03
Foundation	US$/W	0.08
Installation	US$/W	0.10
Civil	US$/W	0.04
Transformer	US$/W	0.08
Land	US$/W	0.04
PM & EPC	US$/W	0.10
Total	US$/W	1.37
CAPEX Fix	%	15
CAPEX dependent on size	%	85
OPEX – annual	US$/W/a	0.02

Table D.4: System size CAPEX assumptions for Wind

System size	Unit	Value
50 MW	US$/W	1.57
100 MW	US$/W	1.37
150 MW	US$/W	1.30
200 MW	US$/W	1.27
300 MW	US$/W	1.23
500 MW	US$/W	1.20
1000 MW	US$/W	1.18

D.4: Economic Assumptions

The following economic assumptions have been used in the supply–demand model to determine the impact on GDP and provincial value creation.

Table D.5: Economic assumptions summary

Item	Unit	Value	Comment
Exchange rate	PRs/US$	300	As of April 2023
Financial assumptions			See Annex Financial Assumptions
Uch I and II, cost	US$/kWh	0.03	SIR, (NEPRA, 2022)
PPA PV, utility-scale	US$/kWh	0.04–0.05	Own simulations
PPA DPV, tube wells	US$/kWh	0.080	Own simulations
PPA wind	US$/kWh	0.045	Own simulations
PPA CSP (night)	US$/kWh	0.100	Literature, adaptation
PPA PV + BESS	US$/kWh	0.123	Own simulations
RE for mining – off-grid	US$/kWh	0.110	Own simulations
PPA RE H2 Production – export	US$/kWh	0.055	Assumption
PPA HPP (comparison case)	US$/kWh	0.080	NTDC IGCEP 2022, including grid
Price CASA – export	US$/kWh	0.060	Assumption – same as the purchase price
Cost basket – import from CPPA	US$/kWh	0.100	Assumption for Provincial GDP
Price export to CPPA	US$/kWh	0.045	Assumption for Provincial GDP
Margin developer	% of PPA	5.0	
Margin province	% of PPA	0.5	

Table D.6: Economic analysis definitions

Item	Unit	Value	Definition
Balochistan (Bal.) RE Electricity Prod.	GWh/a	case	All VRE produced in Balochistan as per case simulation
Bal. Electricity Imp.	GWh/a		All electricity import needed as per hourly case simulation
Bal. Electricity Exp.	GWh/a		All electricity exports incl. Uch I, II as per case simulation
Bal. Electricity sales	US$, millions/year		All electricity revenues by QESCO as per case simulation
Bal. Cost supply	US$, millions/year		All costs of supply using the above assumptions and GWh/year
Bal. Dev. profit	US$, millions/year		5% of the annual PPA assumption
Bal. Industr. profit	US$, millions/year		Simulated cost savings for mining; Assumed green H2 profits
Bal. Jobs Income	US$, millions/year		US$4000/year assumed per average job x new jobs
Balochistan value	US$, millions/year		The sum of 5 lines above + US$191 million as negative base case value due to higher cost of electricity than revenues due to subsidies and nonpayment by farmers
CPPA value	US$, millions/year		Value of Balochistan exports versus US$0.08/kWh for new HPP as an alternative cost of power and DPV benefits
Balochistan GDP	US$, millions/year		Change in GDP. value consumptions of residential and governmental electricity, new local jobs induced GDP, + electricity exports minus electricity imports + US$171 million as negative base case value due to higher electricity imports
RE Jobs O&M	#/a		New direct jobs created x-factor of 1.7, please see above
GHG reductions	MT/a		Assumed 700 g/kWh as an average for replaced gas (500) and coal (900-1000) g/kWh
PV Utility	MWp		As per case simulation
PV Distrib.	MWp		As per case simulation
Wind	MW		As per case simulation
CSP	MW		As per case simulation
CAPEX	US$, millions		As per case simulation, please refer to case studies for details of single opportunities
Economic NPV @ 12.5%	US$, millions		Assumes 20 20-year lifetime of VRE opportunities at a 12.5% discount rate
Economic IRR (no IPPs)	percent		Assumes Pakistan / CPPA invests itself, the amortized IPP WACC of 12.3% is included in the benefits
Economic Payback (no IPPs)	years		Divides the CAPEX by annual benefits in addition to saved WACC

D.5 Economic details of options

The following tables show the electricity supply–demand balance of Balochistan for the developed options

Table D.7: Economic supply–demand balance, Baseline

2027/28	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	0	0	0	0.000		0	0
DPV	0	0	0	0.000		0	0
Wind	0	0	0	0.000		0	0
CSP	0	0	0	0.000		0	0
Uch I + II	930	7,088	213	0.030			
Import from Pakistan excl Uch	0	3,896	390	0.100			
Total Supply		10,984	602	0.055			
Res/Com/Ind		2,662	266	0.100			
Agriculture		5,472	55	0.010			
Mining		0	0	0.000	0.20	0	
Green H2		0	0	0.000		0	
Uch I+II Export		2,850	86	0.030			
Export to Pakistan excl Uch		0	0	0.000	0.08	0	
Curtailm		0	0	0.000			
Total Sales		10,984	406	0.037			
Net Margin Electricity	MUSD		-196			0	
Bal. Developer Profit	MUSD		0				
Bal. Industry Profit	MUSD		0				
Bal. Jobs Income	MUSD		0				
Profit Region	MUSD		-196				
CPPA Profit	MUSD		0				
GDP Province	MUSD		-171				
Jobs created	#		0				

Table D.8: Economic supply–demand balance, PV Utility scale

2027/28	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	4,820	10,942	504	0.046		25	5,182
DPV	0	0	0	0.000		0	0
Wind	0	0	0	0.000		0	0
CSP	0	0	0	0.000		0	0
Uch I + II	930	6,877	206	0.030			
Import from Pakistan excl Uch	0	1,491	149	0.100			
Total Supply		19,311	860	0.045			
Res/Com/Ind		2,662	266	0.100			
Agriculture		5,472	55	0.010			
Mining		0	0	0.000	0.20	0	
Green H2		0	0	0.000		0	
Uch I+II Export		5,205	156	0.030			
Export to Pakistan excl Uch		5,972	328	0.055	0.08	149	
Curtailm		0	0	0.000			
Total Sales		19,311	806	0.042			
Net Margin Electricity	MUSD		-54			175	
Bal. Developer Profit	MUSD		25				
Bal. Industry Profit	MUSD		0				
Bal. Jobs Income	MUSD		35				
Profit Region	MUSD		6				
CPPA Profit	MUSD		149				
GDP Province	MUSD		662				
Jobs created	#		8,809				

Table D.9: Economic supply–demand balance, CSP

2027/28	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	4,820	10,942	504	0.046		25	5,182
DPV	0	0	0	0.000		0	0
Wind	0	0	0	0.000		0	0
CSP	227	1,036	104	0.100		5	568
Uch I + II	930	6,877	206	0.030			
Import from Pakistan excl Uch	0	1,078	108	0.100			
Total Supply		19,934	922	0.046			
Res/Com/Ind		2,662	266	0.100			
Agriculture		5,472	55	0.010			
Mining		0	0	0.000	0.20	0	
Green H2		0	0	0.000		0	
Uch I+II Export		5,706	171	0.030			
Export to Pakistan excl Uch		6,094	335	0.055	0.08	152	
Curtailm		0	0	0.000			
Total Sales		19,934	827	0.042			
Net Margin Electricity	MUSD		-95			183	
Bal. Developer Profit	MUSD		30				
Bal. Industry Profit	MUSD		0				
Bal. Jobs Income	MUSD		39				
Profit Region	MUSD		-25				
CPPA Profit	MUSD		152				
GDP Province	MUSD		747				
Jobs created	#		9,773				

Table D.10: Economic supply–demand balance, Mining

2027/28	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	5,120	11,637	541	0.046		27	5,504
DPV	0	0	0	0.000		0	0
Wind	250	974	63	0.065		3	456
CSP	227	1,036	104	0.100		5	568
Uch I + II	930	6,654	200	0.030			
Import from Pakistan excl Uch	0	1,235	124	0.100			
Total Supply		21,536	1,031	0.048			
Res/Com/Ind		2,662	266	0.100			
Agriculture		5,472	55	0.010			
Mining		1,533	169	0.110	0.20	138	
Green H2		0	0	0.000		0	
Uch I+II Export		5,433	163	0.030			
Export to Pakistan excl Uch		6,436	354	0.055	0.08	161	
Curtailm		0	0	0.000			
Total Sales		21,536	1,007	0.047			
Net Margin Electricity	MUSD		-24			334	
Bal. Developer Profit	MUSD		35				
Bal. Industry Profit	MUSD		138				
Bal. Jobs Income	MUSD		44				
Profit Region	MUSD		193				
CPPA Profit	MUSD		161				
GDP Province	MUSD		771				
Jobs created	#		11,097				

Table D.11: Economic supply–demand balance, 75% DPV[62]

2027/28	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	5,120	11,637	541	0.046		27	5,504
DPV	1,307	2,055	164	0.080		8	2,712
Wind	250	974	63	0.065		3	456
CSP	227	1,036	104	0.100		5	568
Uch I + II	930	5,556	167	0.030			
Import from Pakistan excl Uch	0	402	40	0.100			
Total Supply		21,660	1,079	0.050			
Res/Com/Ind		2,662	266	0.100			
Agriculture		3,464	179	0.052			
Mining		1,533	169	0.110	0.20	138	
Green H2		0	0	0.000		0	
Uch I+II Export		5,266	158	0.030			
Export to Pakistan excl Uch		8,578	472	0.055	0.08	214	
Curtailm		156	0	0.000			
Total Sales		21,660	1,243	0.057			
Net Margin Electricity	MUSD		164			396	
Bal. Developer Profit	MUSD		44				
Bal. Industry Profit	MUSD		138				
Bal. Jobs Income	MUSD		63				
Profit Region	MUSD		408				
CPPA Profit	MUSD		338				
GDP Province	MUSD		1,068				
Jobs created	#		15,707				

62 The options include the impact of energy efficiency through new motors and pumps. It is further assumed that farmers will pay for an adequate electricity supply.

Table D.12: Economic supply–demand balance, 75% DPV, isolated

2027/28	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	0	0	0	0.000		0	0
DPV	1,307	2,055	164	0.080		8	2,712
Wind	0	0	0	0.000		0	0
CSP	0	0	0	0.000		0	0
Uch I + II	930	7,088	213	0.030			
Import from Pakistan excl Uch	0	1,950	195	0.100			
Total Supply		11,093	572	0.052			
Res/Com/Ind		2,662	266	0.100			
Agriculture		3,464	179	0.052			
Mining		0	0	0.000	0.20	0	
Green H2		0	0	0.000		0	
Uch I+II Export		4,966	149	0.030			
Export to Pakistan excl Uch		0	0	0.000	0.08	0	
Curtailm		0	0	0.000			
Total Sales		11,093	594	0.054			
Net Margin Electricity	MUSD		22			8	
Bal. Developer Profit	MUSD		8				
Bal. Industry Profit	MUSD		0				
Bal. Jobs Income	MUSD		18				
Profit Region	MUSD		48				
CPPA Profit	MUSD		124				
GDP Province	MUSD		189				
Jobs created	#		4,610				

Table D.13: Economic supply–demand balance, DPV 2032/33

2032/33	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	5,420	12,331	577	0.047		29	5,827
DPV	1,307	2,055	164	0.080		8	2,712
Wind	500	1,948	127	0.065		6	913
CSP	227	1,036	104	0.100		5	568
Uch I + II	930	5,662	170	0.030			
Import from Pakistan excl Uch	0	861	86	0.100			
Total Supply		23,892	1,228	0.051			
Res/Com/Ind		3,806	381	0.100			
Agriculture		3,799	182	0.048			
Mining		3,110	280	0.090	0.20	342	
Green H2		0	0	0.000		0	
Uch I+II Export		5,057	152	0.030			
Export to Pakistan excl Uch		8,051	443	0.055	0.08	201	
Curtailm		69	0	0.000			
Total Sales		23,892	1,437	0.060			
Net Margin Electricity	MUSD		209			592	
Bal. Developer Profit	MUSD		49				
Bal. Industry Profit	MUSD		342				
Bal. Jobs Income	MUSD		68				
Profit Region	MUSD		668				
CPPA Profit	MUSD		328				
GDP Province	MUSD		1,079				
Jobs created	#		17,031				

Table D.14: Economic supply–demand balance, GW Park

2032/33	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	9,420	23,903	1,294	0.054		65	7,977
DPV	1,307	2,055	164	0.080		8	2,712
Wind	3,500	17,528	1,139	0.065		57	3,650
CSP	227	1,036	104	0.100		5	568
Uch I + II	930	5,066	152	0.030			
Import from Pakistan excl Uch	0	0	0	0.000			
Total Supply		49,588	2,854	0.058			
Res/Com/Ind		3,806	381	0.100			
Agriculture		3,799	182	0.048			
Mining		3,110	280	0.090	0.20	342	
Green H2		0	0	0.000		0	
Uch I+II Export		5,066	152	0.030			
Export to Pakistan excl Uch		32,380	1,781	0.055	0.08	809	
Curtailm		1,427	0	0.000			
Total Sales		49,588	2,775	0.056			
Net Margin Electricity	MUSD		-78			1,287	
Bal. Developer Profit	MUSD		135				
Bal. Industry Profit	MUSD		342				
Bal. Jobs Income	MUSD		101				
Profit Region	MUSD		500				
CPPA Profit	MUSD		936				
GDP Province	MUSD		2,689				
Jobs created	#		25,340				

Table D.15: Economic supply–demand balance, Hydrogen/Ammonia

2032/33	Electricity Balance			Alt Cost	Alt Value	Direct Jobs	
	Capacity	GWh	MUSD	USD/kWh	USD/kWh	USD	#
PV utility scale	9,420	23,903	1,294	0.054		65	7,977
DPV	1,307	2,055	164	0.080		8	2,712
Wind	3,500	17,528	1,139	0.065		57	3,650
CSP	227	1,036	104	0.100		5	568
Uch I + II	930	5,958	179	0.030			
Import from Pakistan excl Uch	0	0	0	0.000			
Total Supply		50,480	2,880	0.057			
Res/Com/Ind		3,806	381	0.100			
Agriculture		3,799	182	0.048			
Mining		3,110	280	0.090	0.20	342	
Green H2		5,046	252	0.050		50	
Uch I+II Export		5,954	179	0.030			
Export to Pakistan excl Uch		28,505	1,568	0.055	0.08	713	
Curtailm		260	0	0.000			
Total Sales		50,480	2,841	0.056			
Net Margin Electricity	MUSD		-39			1,240	
Bal. Developer Profit	MUSD		135				
Bal. Industry Profit	MUSD		393				
Bal. Jobs Income	MUSD		108				
Profit Region	MUSD		596				
CPPA Profit	MUSD		839				
GDP Province	MUSD		3,298				
Jobs created	#		27,040				

D6: Mining statistics

Table D.16: Production figures of minerals in Balochistan from Jan 2022 to June 2022 (in metric tons).

SN	Mineral Type	District	JAN	FEB	MAR	APR	MAY	JUN
1	Coal	Quetta	37,212	43,248	80,951	55,473	51,827	65,513
		Bolan	11,542	11,655	15,275	19,069	11,612	14,988
		Duki	129,364	114,673	163,908	187,701	147,102	161,625
		Harnai	65,027	73,480	101,518	62,349	57,552	81,589
		Total	243,144	243,056	361,651	324,591	268,094	323,715
2	Marble	Khuzdar	46,238	50,531	60,984	42,372	32,201	44,971
		Lasbela	144,120	76,929	168,441	84,654	63,273	128,510
		Loralai	0	0	45	80	0	0
		Bolan		35			41	132
		Chagai	43	82	48	0	48	0
		Total	190,401	127,577	229,518	127,106	95,563	173,613
3	Limestone	Lasbela	543,703	497,972	530,090	492,634	406,982	436,288
4	Serpentine	Lasbela	0	0	0	0	0	0
5	Iron Ore	Chagai	12,175	13,706	11,690	5,448	6,496	5,098
		Khuzdar	0	0	0	0	0	0
		Lasbela	7,136	6,335	1,845	6,985	5,211	8,965
		Total	19,311	20,041	13,535	12,433	11,707	14,063
6	Chromite	Killa Saifullah	7,241	14,338	21,342	13,653	14,604	14,061
		Chagai	147	475	939	342	218	493
		Khuzdar	0	0	0	0	0	15
		Total	7,388	14,813	22,281	13,995	14,822	14,569
7	Magnesite	Killa Saifullah	37	0	0	0	0	0
8	Barite	Chagai	0	0	210	0	0	0
		Khuzdar	24,524	7,799	5,410	8,407	12,689	19,357
9	Pumice	Chagai	896	1,121	740	466	191	411
10	Manganese	Khuzdar						
		Chagai	0	0	94	0	0	0
11	Marbleoynx	Chagai	377	1,670	1,192	259	119	250
12	Sulfur	Chagai	0	0	0	0	0	0
13	Granite	Chagai	589	704	162	392	153	118
14	Fluorite	Mastung						
		Khuzdar						
		Loralai	2,598	1,215	737	861	445	883
15	Copper	Chagai	71	0	520	314	0	165
		Killa Saifullah	0	0	0	0	0	0
16	Basalt	Lasbela	2,684	2,543	2,708	2,676	2,643	2,494
17	Shale	Lasbela	159,635	149,946	137,380	139,871	66,645	136,814
18	Travertine	Loralai	1,239	748	744	1,012	1,518	2,671

Source: Mining data from Department of Minerals and Mining Balochista

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