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Pathways Toward Affordable, Resilient and Greater Indigenous Energy Self-Reliance

Sustainable Energy Systems And Energy Security In Pakistan

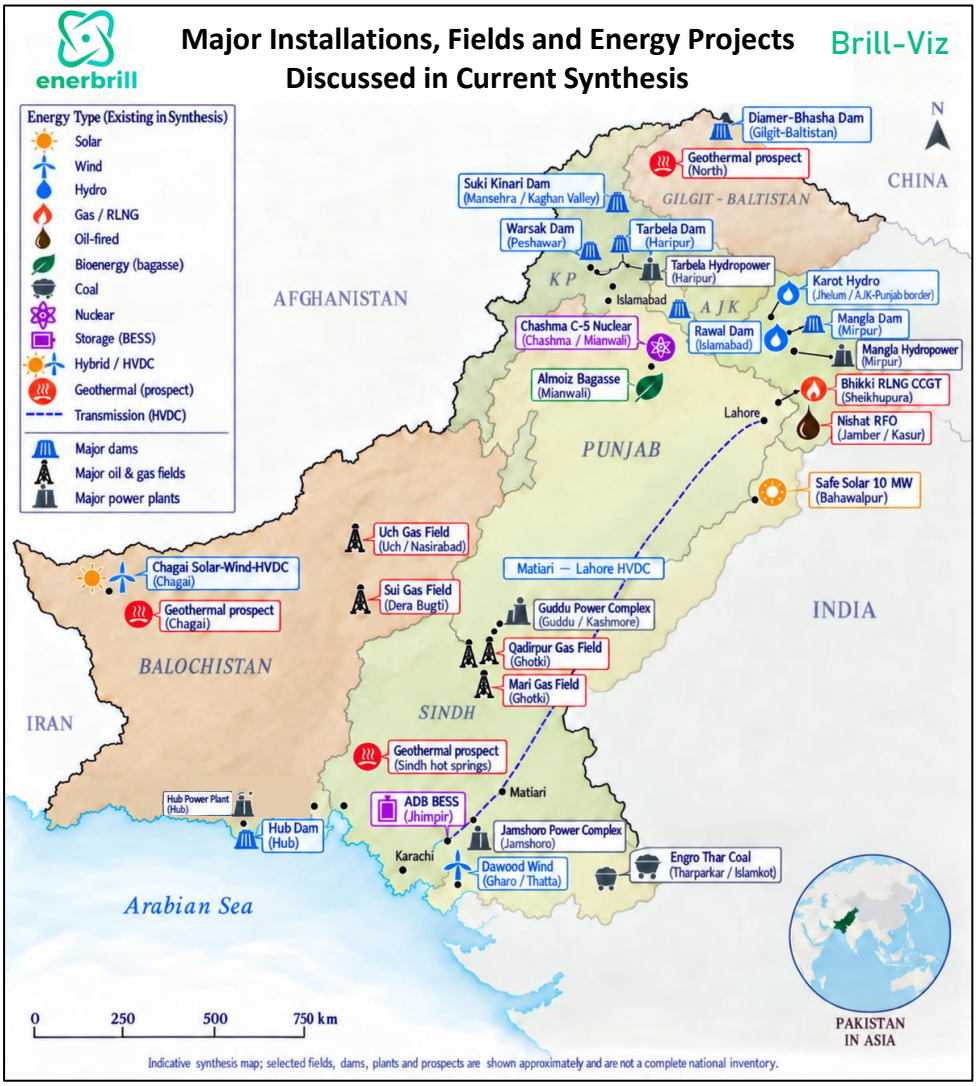
A Global Comparative Synthesis of Resources, Economics, Technology and Utilization

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Sustainable Energy Systems and Energy Security in Pakistan



Abstract

Pakistan's energy challenge is not fundamentally a shortage of installed generating capacity, but a system-level problem arising from declining indigenous hydrocarbon deliverability, growing fuel-import and foreign-exchange exposure, inefficient asset utilization, transmission and distribution constraints, water stress, financing cost, reliability requirements and consumer affordability. This synthesis was undertaken to determine how Pakistan can strengthen long-term energy security and economic resilience by using its indigenous resources, existing infrastructure and technical capabilities more productively while reducing avoidable dependence on imported fuels. Its objectives are to establish a current evidence-based national energy baseline; assess the technical, economic, resource, water and system implications of major energy options; identify lessons transferable from international experience; distinguish commercially actionable opportunities from those requiring further validation; and develop an adaptable framework for resource development, investment, policy and long-term energy-system planning.

The synthesis is grounded in a broad evidence base rather than in any single previous study. The Pakistan Energy Yearbook 2024-25 provides the principal complete annual statistical baseline for the current energy system, while the Pakistan Energy Outlook 2021-2030 and the Ministry of Energy Year Book 2023-24 provide complementary planning, modelling, administrative and implementation context. Pakistan-focused technical and analytical literature, including

Kanwal, Khan and Rauf (2020) and Khan, M. R. (2024), contributes earlier renewable-resource, infrastructure, energy-mix and comparative perspectives. These along with several other sources are integrated with current regulatory and project records, standardized international technology and cost benchmarks, open-access geoscience evidence and publicly available project-finance information. Earlier studies are therefore used to establish context, identify hypotheses and provide comparative interpretations rather than as substitutes for current official observations.

International experience is then used through a functional comparator framework rather than by treating another country's energy mix as a model to copy. Comparator cases identify mechanisms that have addressed particular energy-system problems, including indigenous-resource development, technological change, geothermal exploration-risk sharing, renewable-energy integration, hydro flexibility and dry-year management, direct geothermal heat, transmission development, industrial scale and institutional capability. These lessons are tested against Pakistan's geology, water availability, infrastructure, financing conditions and demand structure. The resulting approach emphasizes adaptation rather than imitation: the relevant question is not what percentage of coal, gas, hydro, wind or solar another country uses, but what conditions made a resource technically useful, commercially deliverable and systemically valuable.

The evidence base integrates the Pakistan Energy Yearbook 2024-25 with official power-sector, petroleum, water and infrastructure records, standardized international technology benchmarks, open-access geoscience evidence and publicly available project-finance information. Hydrothermal geothermal, hydropower, solar, wind, coal, natural gas and RLNG, residual furnace oil, nuclear energy, bioenergy, battery storage, transmission investment and demand-side efficiency are evaluated within a common evidence architecture. Reported observations are separated from derived calculations and forward scenarios. Brill-Viz is used to support comparative analytics and evidence-gated project economics through full-life and point-forward cash-flow evaluation, sensitivity and uncertainty analysis. An Investor-Consumer Bankability Window links project investability with the economic value that a project can reasonably deliver to the power system and consumers, while incomplete economic cases are explicitly gated rather than completed using unsupported assumptions.

The synthesis finds that Pakistan's energy vulnerability is increasingly defined by the gap between domestic resource delivery and energy demand. In FY2024-25, indigenous energy production declined to about 50 MTOE while imports increased to about 34 MTOE, and gross electricity generation reached 140.42 TWh. Continued oil and gas exploration and new discoveries remain strategically important, but have not by themselves reversed the decline in domestic production; reserve replacement must therefore ultimately be judged by **commercially deliverable production rather than discovery counts alone**. Imported oil and LNG continue to expose the economy to international price, supply and foreign-exchange risk. At the same time, plant utilization, capacity-payment dilution, network losses, curtailment, transmission capability, hydrological variability and water availability show that installed capacity alone is an inadequate measure of security. Energy saved, losses avoided, existing assets better utilized and indigenous production sustained can therefore have system value comparable with some additions of new generation.

The synthesis concludes that no single technology or foreign energy model provides a defensible national solution. Pakistan's stronger pathway is a **regionally differentiated, progressively diversified and evidence-gated portfolio** combining continued hydrocarbon exploration and brownfield productivity with competitive solar and wind, hydropower and nuclear firming, selective and efficient use of indigenous thermal resources, staged geothermal exploration, sustainable bioenergy, appropriately located storage, strengthened transmission, improved asset utilization and aggressive demand-side efficiency. Diversification should not be interpreted as abandonment of oil and gas exploration; rather, reducing unnecessary consumption of scarce domestic hydrocarbons can preserve their economic and strategic value while replacement reserves are pursued.

The central implication is that Pakistan's energy strategy should shift from simply adding capacity toward maximizing **resource productivity, system efficiency, indigenous energy delivery and useful economic output per unit of investment, imported fuel, domestic resource and water consumed**. International comparisons provide practices and decision conditions, not technology quotas, while project economics determine whether those practices remain investable and affordable under Pakistan-specific conditions. Because a complete current 8,760-hour demand, unit-dispatch, hydrology, outage and nodal-transfer dataset is not yet available in an integrated form, the 2030-2050 pathways remain transparent screening scenarios rather than a uniquely proven least-cost optimum. The synthesis is

therefore intended to serve as a **living national evidence framework** for energy-security planning, project screening, investment prioritization and future chronological system optimization, capable of being strengthened as new petroleum reserves, resource measurements, operating data and project-economic evidence become available.

Keywords: Pakistan; energy security; sustainable energy systems; indigenous resources; comparative energy systems; resource productivity; oil and gas reserve replacement; import dependence; geothermal; hydropower; solar; wind; natural gas; RLNG; coal; nuclear energy; bioenergy; battery storage; transmission; energy efficiency; water-energy nexus; project economics; energy-system resilience.

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Evidence and reproducibility statement

Reported observations, derived calculations, model/scenario results and integrated interpretations are kept distinct. Critical quantitative claims prioritize official Pakistani records, standardized international datasets, peer-reviewed studies and public project or financing documents. Quantitative inputs used for analytical figures are retained with period, unit, source and evidence class in the companion database. Comparator-derived prospective economics are additionally tagged as scenario evidence and remain separate from observed Pakistan project costs.

PART I - INTRODUCTION AND METHODOLOGY

1. Introduction

1.1 Background and rationale

Pakistan's energy challenge is often framed as a shortage of generation capacity or as a debate over which single fuel should dominate the national mix. That framing is too narrow for the present project. Energy security is a system property. It depends simultaneously on the physical resource base, generation and conversion technology, fuel and foreign-exchange exposure, grid capability, water availability, utilization rate, demand structure, financing cost, environmental limits, and the price ultimately paid by consumers.

The current power system illustrates why capacity alone is an insufficient metric. As of March 2026, Pakistan reported 49,651 MW of installed electricity capacity, including 10,101 MW classified as renewable capacity. During July-March FY2026, however, electricity generation totalled 92,835 GWh and the renewable category contributed 4.5% of generation, while hydel and nuclear contributed a further 48.6%. The capacity figure also includes 7,319 MW of net-metering capacity. Installed capacity, grid generation and behind-the-meter production therefore cannot be interpreted as directly interchangeable measures of system contribution (Government of Pakistan, 2026, Tables 14.1-14.2).

At the same time, Pakistan remains exposed to imported energy and to domestic resource depletion. The Pakistan Economic Survey identifies continuing petroleum import dependence and declining indigenous natural-gas production and depletion pressure in mature fields as material concerns, while also describing policy efforts to expand indigenous, renewable and lower-cost resources. The research problem is consequently not whether Pakistan should choose one fuel over another. It is how to construct a portfolio that reduces avoidable import exposure without creating new problems of water stress, grid instability, unaffordable tariffs or unbankable projects.

1.2 Purpose and central objective

The central objective is to determine which combinations of indigenous and imported energy resources can provide Pakistan with the lowest defensible long-term system cost, acceptable reliability, reduced foreign-exchange exposure, and acceptable water and environmental performance while remaining investable for project developers and affordable for users.

The study is deliberately broader than an electricity-generation review. Electricity is a major component, but the analysis also considers petroleum products, gas, direct heat, transport and industrial energy, storage, transmission, efficiency, and the water-energy nexus. Geothermal and hydrothermal resources receive special attention because they potentially connect Pakistan's subsurface knowledge, oil-and-gas technical capability, direct-use heat opportunities and the need for firm low-carbon energy.

1.3 From previous Pakistan energy literature and official evidence to system synthesis

Pakistan's energy literature and official planning records provide several complementary foundations for the present study, but they serve different analytical purposes. The **Pakistan Energy Yearbook 2024-25** provides the principal recent complete-year statistical baseline for national energy production, imports, electricity generation and consumption, fuel supply and related system indicators. The **Pakistan Energy Outlook 2021-2030** provides an earlier official planning and modelling framework and is retained as a historical forecast benchmark rather than treated as current observation. The **Ministry of Energy Year Book 2023-24** provides an administrative and implementation checkpoint for institutions, projects, transmission development, net metering and sector programmes.

Published research adds complementary resource, technology and policy perspectives. **Kanwal, Khan and Rauf (2020)** synthesized Pakistan's renewable-energy potential and infrastructure, including solar, wind, biomass, geothermal resources and smart-grid development, and emphasized the importance of stronger renewable-energy integration. **Khan, M. R. (2024)** compared Pakistan's energy mix with those of India, China and the United States and raised the broader question of how indigenous-resource utilization, particularly coal and declining domestic gas supply, relates to import dependence and energy security.

Neither study is treated here as the primary quantitative foundation for the present synthesis. Kanwal et al. (2020) represents an important earlier renewable-resource and infrastructure review, while Khan (2024) provides a useful comparative question and source of hypotheses. The present work instead integrates these and other published interpretations with newer official statistics, regulatory evidence, project records, water and infrastructure data, international benchmarks and project-economics evidence.

The analytical question is consequently broadened from **which resources Pakistan possesses, or how its national energy mix differs from those of other countries, to the conditions under which resources, technologies, existing assets, network investments and demand-side interventions become technically useful, commercially deliverable, systemically valuable, financially bankable and affordable**.

Accordingly, international comparison is organized around transferable system functions rather than national fuel shares. Countries are compared where they demonstrate relevant capabilities such as geothermal exploration-risk sharing, variable-renewable integration, reservoir management, direct-use heat, flexible hydropower, transmission planning, indigenous-resource development or industrial scale. No foreign model is assumed to be transferable to Pakistan without explicit testing of geological, financial, water, grid, infrastructure and institutional differences.

1.4 Scope

The resource scope includes hydropower and pumped storage, solar PV, wind, conventional hydrothermal geothermal, direct geothermal heat, next-generation geothermal where technically relevant, nuclear power, indigenous coal, domestic gas, imported LNG, residual furnace oil (RFO) and other petroleum products, biomass, biogas, waste-to-energy, batteries and other storage, transmission, demand-side efficiency and selected electrification pathways.

The temporal scope has three levels. First, the study establishes the current and recent historical baseline. Second, it reconstructs technology and policy trajectories from published time series where the data are comparable. Third, it evaluates alternative 2030, 2040 and 2050 pathways, explicitly treated as scenarios rather than forecasts.

1.5 Key definitions

Energy security in this study means the ability of the energy system to provide reliable and affordable energy with manageable exposure to supply disruption, fuel-price volatility, foreign-exchange constraints, infrastructure failure and environmental or water limitations. Energy self-reliance means reducing avoidable external dependence by using technically and economically defensible domestic resources; it does not imply autarky or the elimination of all imports.

Sustainability is treated as a multidimensional constraint rather than a label. A project can be low-carbon but water-intensive, indigenous but high-emission, low-LCOE but variable, or technically attractive but financially unbankable. The synthesis therefore evaluates trade-offs explicitly rather than assigning a technology a single qualitative category.

The term hydrothermal geothermal refers to naturally occurring hot-water or steam systems and is kept distinct from hydropower, which converts hydraulic head and water flow into electricity. This distinction is important because both are water-related but have fundamentally different resource, reservoir and infrastructure requirements.

1.6 Scientific, economic and practical significance

The scientific contribution is the integration of subsurface resource evidence, hydrology, power-system data and economics into one traceable framework. The economic contribution is the use of common project-finance metrics across unlike technologies while preserving the differences in exploration risk, capacity factor, fuel exposure and system value. The practical contribution is intended to be a prioritized, region-specific roadmap rather than a generic national list of technologies.

The study also provides a direct real-world application for Brill-Viz. The Geoscience, Wells & Energy Analytics template can act as the technical and resource-analysis layer, while the Brill-Viz Economics template can evaluate CAPEX, OPEX, tariff, cash flow, NPV, IRR, LCOE, sensitivity and uncertainty. This separation prevents technical-resource indicators from being confused with bankability metrics.

1.7 Regionalization within Pakistan

Pakistan will not be treated as a uniform energy province. Resource quality, water availability, demand density, transmission access, terrain and infrastructure vary strongly among Sindh, Punjab, Balochistan, Khyber Pakhtunkhwa, Gilgit-Baltistan and Azad Jammu and Kashmir. The final recommendations should therefore be regional portfolios whose national synthesis emerges from their integration rather than from a single uniform technology ranking.

1.8 Organization of the synthesis

The first three parts establish the analytical foundation and the Pakistan baseline. Subsequent parts will analyze each resource family, then the grid and demand system, followed by common economics and financing, global comparator cases, regional Pakistan portfolios and integrated scenarios. The database, figures and manuscript will be versioned together so that a change in evidence is traceable through the entire analytical chain.

1.9 Initial research questions

- What is the present physical and economic structure of Pakistan's energy system when capacity, generation, final consumption, imports and sectoral use are separated correctly?
- Which indigenous energy resources can materially reduce imported-fuel exposure without creating unacceptable water, grid, environmental or financing burdens?
- Which global energy systems provide process analogues that are genuinely transferable to Pakistan, and which differences make direct copying inappropriate?
- How should geothermal prospects be ranked when geological prospectivity, reservoir confirmation, drilling risk, water chemistry, grid access and economics are evaluated together?
- How do water scarcity and seasonal hydrology change the ranking of hydropower, thermal generation, geothermal cooling systems, coal, nuclear and solar technologies?
- What combination of solar, wind, hydro, nuclear, geothermal, storage and flexible demand minimizes system cost while preserving reliability?
- How large is the energy-security value of avoided fuel imports and foreign-exchange exposure relative to conventional plant-level LCOE?
- What project structures can satisfy both investor return requirements and consumer/system affordability?
- How should energy portfolios differ across Pakistan's provinces and major resource regions?
- Which interventions in efficiency, grid reinforcement and demand management are economically equivalent to adding new generation?

2. Objectives, Research Questions and Hypotheses

2.1 Study objectives

The study has five linked objectives: build an auditable database with published data; characterize Pakistan's energy and water baseline; compare technologies and operating country analogues on normalized technical and economic terms; quantify project and system economics under Pakistan-specific assumptions; and develop a staged regional and national roadmap that can be updated as new evidence becomes available.

The manuscript is not intended to advocate a predetermined mix. Recommendations will be conditional on evidence and will state the assumptions under which a technology or project becomes preferred.

2.2 Core testable hypotheses

Table 2.1. Core research hypotheses and discriminating evidence.

ID	Research hypothesis	Status	Discriminating evidence
E1	Pakistan energy self-reliance is a portfolio-optimization problem rather than a single-technology problem.	Supported directionally	Realized cross-technology cost/utilization reinforces portfolio optimization; a primary 8,760-hour optimum remains unproven.
E2	Hydrothermal/geothermal is a plausible but under-characterized indigenous firm/heat resource; bankability requires direct subsurface validation.	Partly supported	No new flow/injectivity or drilling confirmation; geothermal remains a staged resource-validation proposition.
E3	Water scarcity materially changes the optimal ranking of technologies, cooling systems and sites.	Partly supported	Chashma water-supply evidence strengthens the water constraint, but site-specific consumptive-use data remain incomplete.
E4	Public or concessional sharing of early geothermal exploration risk can unlock private capital more efficiently than fully private wildcat drilling.	Partly supported	Global exploration-risk sharing remains a credible analogue; a Pakistan mechanism remains to be designed and tested.
E5	Low-cost solar and wind require grid, firming and flexibility resources; hydro, nuclear, validated geothermal, storage and demand response can provide complementary system functions.	Supported directionally	Annual utilization/cost plus current grid evidence confirms the need to value energy, capacity, flexibility and network services together.
E6	Direct geothermal heat can be economic at resource temperatures below those required for efficient power generation.	Untested / future pilot question	No new Pakistan direct-geothermal-heat demand and bankability evidence was acquired.
E7	Energy-security value includes avoided foreign exchange, fuel-price volatility and reliability value, not only plant LCOE.	Supported directionally	Local/imported coal and RLNG evidence make fuel and foreign-exchange exposure more measurable; full forward avoided-import valuation remains incomplete.
E8	Optimal energy portfolios differ materially among Pakistan's provinces and resource regions.	Partly supported	Regional resource, grid and water differences remain clear; optimized regional chronological allocation remains unproven.
E9	An investor-consumer bankability window can objectively test project investability and affordability.	Prototype strengthened, not decision-grade	Current project evidence plus realized performance strengthens the framework, but investor floors and locational system ceilings remain incomplete for most cases.

ID	Research hypothesis	Status	Discriminating evidence
E10	Efficiency, grid investment and demand-side measures can deliver self-reliance benefits comparable with some generation additions.	Supported directionally	Low-utilization fixed-cost dilution and grid-reinforcement evidence show that non-generation interventions can avoid substantial system cost.

2.3 Decision standard

A hypothesis will not be accepted because it is intuitively attractive. Each will be assigned a status such as supported, partly supported, unresolved or rejected, with the decisive evidence stated explicitly. Technology recommendations will similarly be conditional on the resource, financing and system conditions under which they are valid.

3. Evidence Base, Data Architecture and Analytical Methodology

3.1 Evidence hierarchy

Evidence is weighted by directness, reproducibility and relevance to the decision being tested. Recency matters for prices, capacity and policy, but it does not automatically make a secondary source stronger than direct measurements or a project financial record.

Two attached official publications are used in different evidence classes. The Pakistan Energy Outlook Report 2021-2030 is treated as a published historical planning and model source: its Integrated Energy Planning database and methodological documentation are useful evidence, while its 2021-2030 outputs remain forecasts rather than observations. The Ministry of Energy Year Book 2023-24 is treated as an official administrative and sector record for institutions, projects, net metering, efficiency programmes and FY2023-24 implementation status. Neither source overrides newer observed 2025-26 data where definitions are comparable (Ministry of Planning, Development & Special Initiatives, 2022; Ministry of Energy (Power Division), 2024).

Table 3.1. Working evidence hierarchy for the energy synthesis.

Level	Evidence class	Examples / use
1	Primary measured / project evidence	Plant generation and outage records; well temperatures and tests; streamflow; project tariff determinations; audited project costs; field geochemistry.
2	Official national statistics and regulatory records	Pakistan Economic Survey; NEPRA; PPIB; WAPDA; NTDC/ISMO; CPPA-G; OGRA; SBP; IRSA; PBS.
3	Standardized international datasets	IRENA; IEA; World Bank/ESMAP; FAO AQUASTAT; IAEA PRIS; NREL/DOE where methods and definitions are explicit.
4	Peer-reviewed technical studies	Resource assessments, geothermal studies, hydrology, technology performance and lifecycle analyses.
5	Feasibility, appraisal and financing documents	World Bank/ADB project appraisal documents; public EPC/tender records; environmental and social assessments.
6	Industry reports and secondary syntheses	Used for context, triangulation and discovery; not sole support for a critical quantitative conclusion where stronger evidence exists.

Pakistan-focused reviews and analytical commentaries are retained within the published-literature evidence class rather than being treated as substitutes for primary or official statistics. Kanwal, Khan and Rauf (2020), for example, provide an earlier synthesis of renewable-resource potential, geothermal evidence and smart-grid development, while Khan, M. R. (2024) provides a comparative energy-mix interpretation and a set of questions concerning indigenous-resource utilization and import exposure. Their value in the present synthesis lies principally in literature context, hypothesis development, comparison and triangulation. Current national quantities are preferentially anchored to the Pakistan Energy Yearbook 2024-25, Pakistan Economic Survey, regulatory records and other period-appropriate official evidence, while the Pakistan Energy Outlook 2021-2030 remains explicitly classified as a historical planning/model source.

3.2 Data architecture

The companion evidence database workbook is the initial master evidence database. Each numeric record stores domain, geography, period, category, metric, value, unit, data type, source identifier, source location and publication/download link. This long-form structure supports reproducible charting while source-specific sheets preserve the original tabular context.

Project-economic tables include project identity, technology, gross and net capacity, annual generation, resource variables, total project cost, EPC cost, infrastructure and interconnection cost, development schedule, fixed and variable O&M, fuel or feedstock, water, tariff/PPA, debt/equity, interest rate, tenor, tax, foreign-exchange and inflation assumptions. Raw published values will be stored separately from normalized values.

3.3 Data-type discipline

Table 3.2. Data types retained separately in the research database.

Data type	Definition	Example
Reported observation	Directly published measured or administrative value.	Pakistan installed capacity; hot-spring chemistry; project COD.
Derived calculation	Calculated from reported inputs using a stated formula.	Implied capacity factor; self-sufficiency ratio; normalized USD/kW.
Model / scenario	Output of an optimization, forecast or resource model.	World Bank 2030 VRE scenario; reservoir property model.
Published interpretation	Author or agency explanation of observations/model results.	Study interpretation of geothermal reservoir potential.
Integrated synthesis	This project's evidence-weighted conclusion.	Technology suitability or regional portfolio recommendation.
Unknown / not reported	No defensible value acquired yet.	Must remain blank, not zero.

3.4 Unit normalization and comparability

Like-for-like comparison requires more than converting units. The study will preserve whether a value is nominal or real, the currency base year, whether capacity is gross or net, whether generation is gross or sent-out, whether water use is withdrawal or consumption, whether hydropower includes pumped storage, and whether costs are plant-only or include transmission, financing and development. Original values and units are retained before normalization.

The companion evidence database dataset already separates installed capacity from generation and final consumption. This distinction is especially important where distributed generation and net metering make the registered capacity base expand faster than reported grid-supplied generation.

3.5 Comparative-analogue method

Countries are selected by function, not because they are assumed to be direct equivalents of Pakistan. Türkiye is relevant to geothermal private investment and exploration-risk sharing; Indonesia illustrates large upstream resource risk; New Zealand illustrates high-utilization geothermal field management; Iceland illustrates direct heat and cascade use; Kenya illustrates public-sector resource de-risking; and the United States illustrates drilling and next-generation geothermal technology. Solar, wind, hydro, nuclear and grid comparator countries are selected using the same function-specific principle.

3.6 Economics method and Brill-Viz workflow

The economics framework begins with annual project cash flow rather than with LCOE alone. Revenue will be generated from energy and, where relevant, capacity or ancillary-service payments. Costs will be separated into development, resource confirmation, EPC, owner's cost, land and site works, grid interconnection, water systems, financing, fixed O&M, variable O&M, fuel or feedstock, fuel levies and logistics where applicable, major replacements, taxes and decommissioning.

Brill-Viz Economics is used to calculate NPV, IRR, MIRR, payback, LCOE or LCOS, breakeven tariff, downside/base/upside cases, tornado sensitivities, two-way sensitivity surfaces and Monte Carlo distributions. Project-resource uncertainty will be treated explicitly for geothermal and other resource-dependent technologies. For fuel-dependent plants, regulatory fuel-price components, levies, freight/handling, exchange-rate exposure and all-in project tariffs are retained as separate evidence fields so a fuel component is not misread as a complete tariff or LCOE.

A central proposed metric is the Investor-Consumer Bankability Window. The investor floor is the tariff or revenue level required to satisfy the study's return and debt-service conditions. The consumer/system ceiling is the maximum economically rational price given avoided fuel imports, system alternatives, reliability value, transmission and integration costs. A project is intrinsically bankable and affordable when the floor is at or below the ceiling; otherwise the gap must be explained and tested against de-risking or concessional-finance options.

3.7 Figures and analytical plots

Figures are treated as analytical evidence, not decoration. The Geoscience, Wells & Energy Analytics template will generate resource, geochemical, water, technology and comparative plots from the published data database. Reference overlays will be used only where a defensible technical basis exists and will be labelled as screening or reference guides rather than universal boundaries. The Economics template will generate project cash-flow and investment figures from a separate but linked economic-input dataset.

3.8 Uncertainty, gaps and update protocol

This synthesis includes an evidence-gap register. High-priority gaps currently include plant- and project-level tariff and CAPEX data, hydro flow and storage time series, spatial solar and wind resource data, transmission constraints and interconnection costs, technology-specific water-use data, a national geothermal inventory beyond the Zindapir case, nuclear project economics, and hourly or monthly load data. These gaps define the acquisition agenda rather than being filled by assumed averages.

PART II - GLOBAL COMPARATIVE FRAMEWORK

4. Global Energy Transition and Technology-Economics Context

4.1 Why the global comparison must be technology- and function-specific

Global energy statistics provide useful benchmarks only when the underlying definitions are comparable. IRENA reports that worldwide renewable power capacity reached 5,149 GW in 2025 after 692 GW of additions, with renewables accounting for 85.6% of global capacity additions that year. These figures demonstrate the scale and pace of deployment,

but they do not by themselves determine which mix is optimal for Pakistan because system value depends on local demand, grid, financing, resource quality and water constraints (IRENA, 2026).

The appropriate comparator question is therefore not “Which country has the highest renewable share?” but “Which country has solved a problem that Pakistan also faces, and what conditions made that solution work?” This study will keep a country-to-Pakistan transferability matrix that records the process being compared, the evidence of performance, and the critical differences that limit direct transfer.

4.2 Cost and utilization benchmarks

IRENA’s 2024 cost database shows a wide range of plant-level economics among renewable technologies. New onshore wind averaged about USD 0.034/kWh, solar PV USD 0.043/kWh, hydropower USD 0.057/kWh and geothermal USD 0.060/kWh. Geothermal’s global weighted-average total installed cost was about USD 4,015/kW and its weighted-average capacity factor for plants commissioned in 2024 was 88%. These values are useful benchmarks, but IRENA explicitly notes that LCOE is a plant-level metric and excludes costs beyond the busbar, including transmission and distribution (IRENA, 2025).

Table 4.1. Global weighted-average renewable cost and performance benchmarks for projects commissioned in 2024.

Technology	Installed cost (2024 USD/kW)	Capacity factor (%)	LCOE (USD/kWh)
Bioenergy	3,242	73	0.087
Geothermal	4,015	88	0.060
Hydropower	2,267	48	0.057
Solar PV	691	17	0.043
CSP	3,677	41	0.092
Onshore Wind	1,041	34	0.034
Offshore Wind	2,852	42	0.079

Source: IRENA (2025), Renewable Power Generation Costs in 2024, Table S1 and technology chapters. Values are global weighted averages for newly commissioned projects and are not Pakistan project estimates.

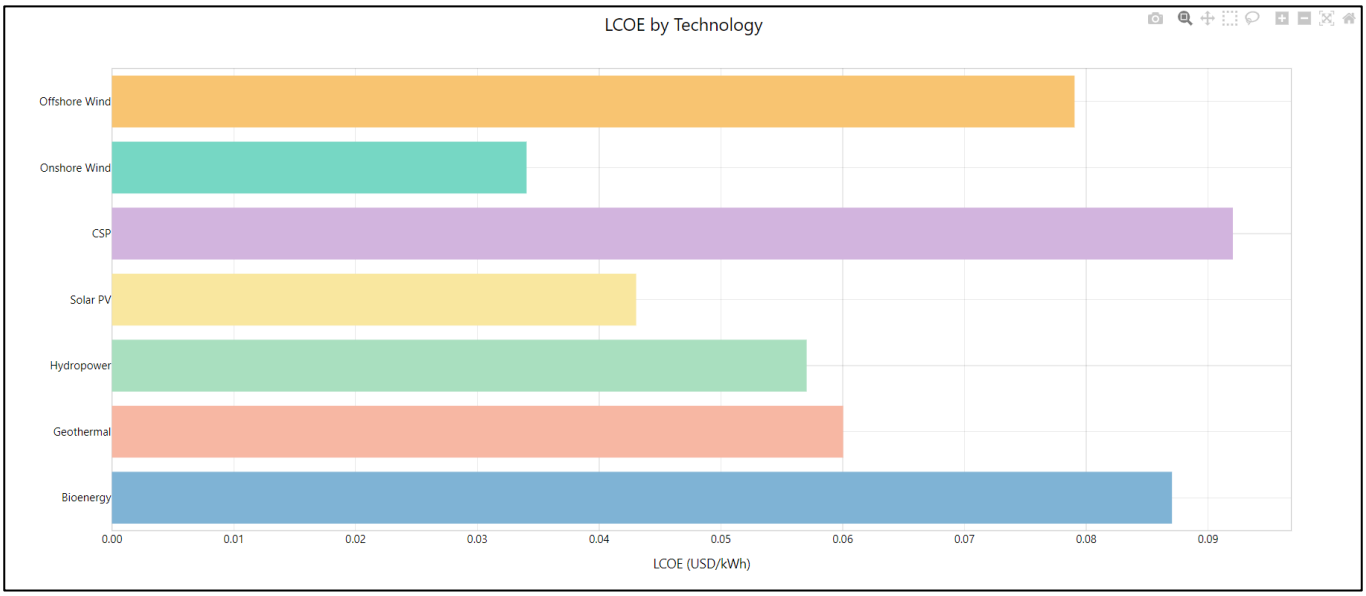


Figure 4.1. Global weighted-average LCOE of newly commissioned renewable projects, 2024.

Source: IRENA (2025). Plant-level LCOE does not include all system, grid or country-specific financing costs.

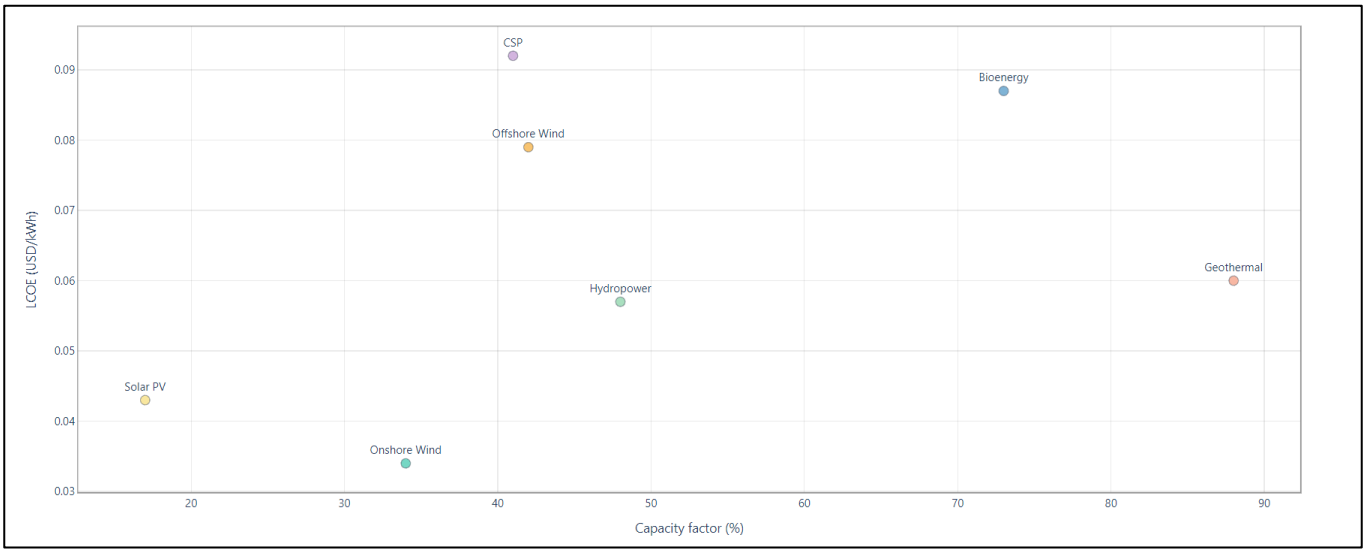


Figure 4.2. Capacity factor versus LCOE for global renewable benchmarks, 2024.

Source: IRENA (2025). The figure illustrates why low plant-level LCOE and high utilization are different dimensions of value.

4.3 Geothermal as a distinct comparator class

Geothermal deserves separate treatment because it combines an upstream resource-development problem with a power or heat project. IRENA reports that only about 320 MW of new geothermal power was commissioned globally in 2024, bringing cumulative capacity to about 15.4 GW at year-end. New plants nevertheless showed an 88% weighted-average capacity factor, illustrating the technology's potential value as a high-utilization resource where a commercial reservoir is proven (IRENA, 2025).

The IEA emphasizes that geothermal can provide firm electricity and heat and that techniques developed in the oil and gas industry, including advanced drilling, can expand the accessible resource base. At the same time, project development remains constrained by exploration risk, permitting, cost and bankability. The IEA therefore recommends risk-mitigation schemes, open geothermal data, long-term revenue certainty and support for direct heat applications (IEA, 2024).

The financing problem is especially important for Pakistan. World Bank geothermal programmes identify exploratory drilling as a central upstream barrier. In Türkiye, a risk-sharing mechanism and long-term loan facility were used to support private-sector geothermal investment; in Indonesia, exploration-risk facilities were designed to absorb part of the loss where resource confirmation fails. These mechanisms will be tested as analogues for a possible Pakistan Geothermal Exploration Risk Facility, but no policy recommendation is adopted at this stage.

4.4 Global analogues selected for later detailed comparison

Table 4.2. Initial global comparator set and the function each comparator is intended to test.

Comparator	Primary lesson to test	Critical caution
Türkiye	Fault/graben geothermal; private investment; exploration-risk sharing and long-term finance.	Geology and project-finance analogue; not a direct resource equivalence.
Indonesia	Large geothermal resource base with high exploration cost and risk-mitigation finance.	Financing and resource-risk analogue.
New Zealand	High geothermal utilization and mature reservoir management.	Operations, reinjection and resource-management analogue.

Comparator	Primary lesson to test	Critical caution
Iceland	Direct heat, district heating and cascade use of geothermal energy.	Direct-use/system-integration analogue; geology differs strongly from Pakistan.
Kenya	Public-sector exploration/de-risking followed by power development.	Institutional and financing analogue.
United States	Oil-and-gas drilling synergies and next-generation geothermal technology.	Technology and drilling analogue.
India / Himalayan region	Regional geology, hydropower and rapidly changing power mix.	Regional-context analogue where definitions and data are comparable.
China	Large-scale solar, wind, hydro, grid and industrial supply chains.	Scale, manufacturing and system-integration analogue, not a simple mix target.

PART III - PAKISTAN ENERGY-WATER BASELINE

5. Pakistan Energy System: Present Baseline

5.1 Installed capacity and generation: FY2024-25 full-year bridge to the March-2026 baseline

As of March 2026, Pakistan's installed electricity capacity was reported at 49,651 MW. Thermal capacity remained the largest category at 24,405 MW (49.2%), followed by hydel at 11,615 MW (23.4%), renewable at 10,101 MW (20.3%) and nuclear at 3,530 MW (7.1%). During July-March FY2026, generation totalled 92,835 GWh: thermal 43,581 GWh (46.9%), hydel 27,961 GWh (30.1%), nuclear 17,133 GWh (18.5%) and renewable 4,160 GWh (4.5%) (Government of Pakistan, 2026, Tables 14.1-14.2).

The Pakistan Energy Yearbook 2024-25 provides the complete annual checkpoint immediately before the March-2026 Economic Survey snapshot. As of 30 June 2025, installed electricity capacity was 45,380 MW and FY2024-25 gross generation was 140,420 GWh, including about 70,110 GWh thermal, 40,404 GWh hydel and 24,208 GWh nuclear generation. These values are retained as a dated full-year baseline and are not mechanically merged with the later March-2026 capacity totals because the reporting period and treatment of distributed/net-metered capacity differ (HDIP, 2026).

The difference between installed renewable capacity share and reported renewable generation share is analytically important. The capacity table includes 7,319 MW from net metering, while the generation table reports system generation by source under a different accounting structure. This synthesis therefore avoids describing the difference simply as "underutilization" until behind-the-meter production, reporting coverage and grid dispatch are reconciled.

Table 5.1. Pakistan installed capacity and electricity generation, Jul-Mar FY2026.

Source	Installed MW	Capacity share %	Generation GWh	Generation share %
Hydel	11,615	23.4	27,961	30.1
Thermal	24,405	49.2	43,581	46.9
Nuclear	3,530	7.1	17,133	18.5
Renewable	10,101	20.3	4,160	4.5

Source: Government of Pakistan (2026), Pakistan Economic Survey 2025-26, Tables 14.1 and 14.2.

Table 5.1A. FY2024-25 full-year national energy/electricity bridge from the Pakistan Energy Yearbook.

Indicator	FY2024-25 value	Unit / basis	Interpretive use	Boundary / caution
Indigenous energy production	~50	MTOE	Self-reliance trend	Rounded executive-summary value; down from ~53 MTOE.
Energy imports	~34	MTOE	Import-dependence trend	Rounded executive-summary value; up from ~33 MTOE.
Installed electricity capacity	45,380	MW at 30-Jun-2025	Pre-March-2026 capacity checkpoint	Do not equate directly with later 49,651 MW snapshot.
Gross electricity generation	140,420	GWh	Full-year generation baseline	Gross generation, not electricity sales.
Electricity consumption	113,139	GWh	Full-year end-use baseline	Public-utilities balance.
T&D losses	35,316 / 23.8%	GWh / % of net supply	Network-loss screening anchor	Boundary differs from CY2026 10.87% units-received/sold forecast.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Executive Summary and Table 5.9. Values are period-specific; loss definitions are preserved as reported.

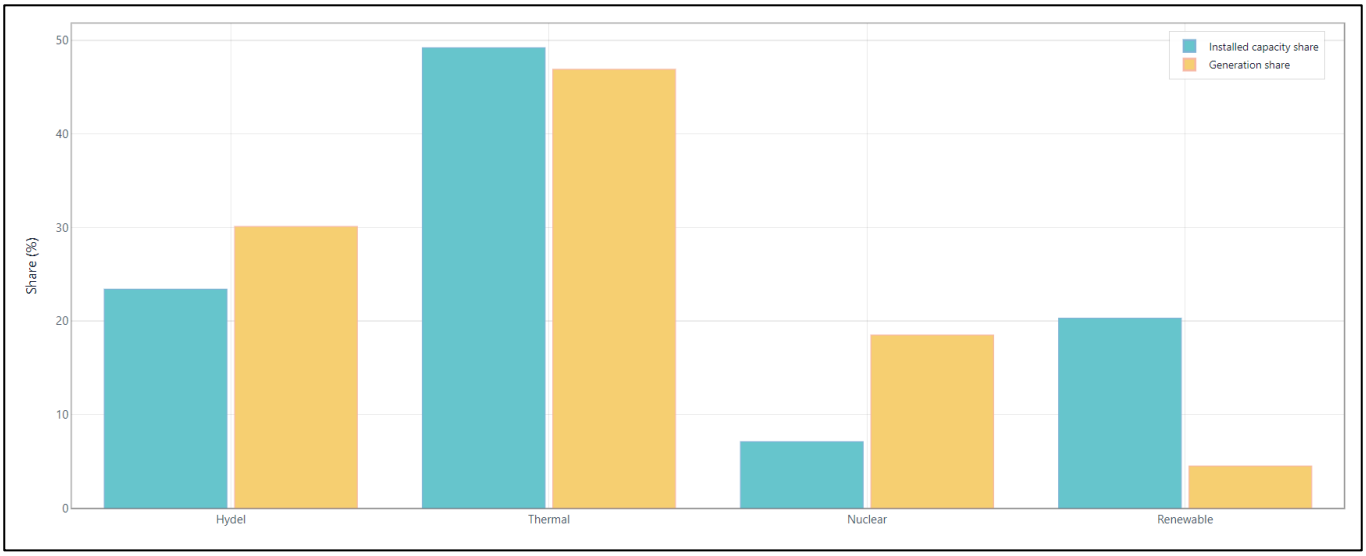


Figure 5.1. Pakistan installed capacity share compared with generation share, Jul-Mar FY2026.

Source: Pakistan Economic Survey 2025-26. Renewable installed capacity includes 7,319 MW of net-metering capacity.

The full-year producer-group view adds an institutional dimension to the generation mix. IPPs supplied 65,743 GWh (about 46.8% of FY2024-25 gross generation), WAPDA 37,120 GWh (26.4%) and PAEC 24,208 GWh (17.2%); K-Electric and the AJKPDO/PEDO/hydel-IPP group supplied the remainder. This concentration does not by itself indicate fuel dependence because the IPP category spans multiple technologies, but it shows that generation planning, dispatch, contracting and transmission policy must be evaluated across institutional as well as fuel categories.

5.2 Electricity consumption and demand structure

Total electricity consumption during July-March FY2026 was reported at 83,143 GWh. Household consumption remained the largest category at 39,472 GWh (47.48%), while industry consumed 26,205 GWh (31.52%). Commercial, agriculture and other uses accounted for the remainder. The industrial share increased relative to the corresponding period of FY2025, while agricultural grid consumption fell sharply (Government of Pakistan, 2026, Table 14.3).

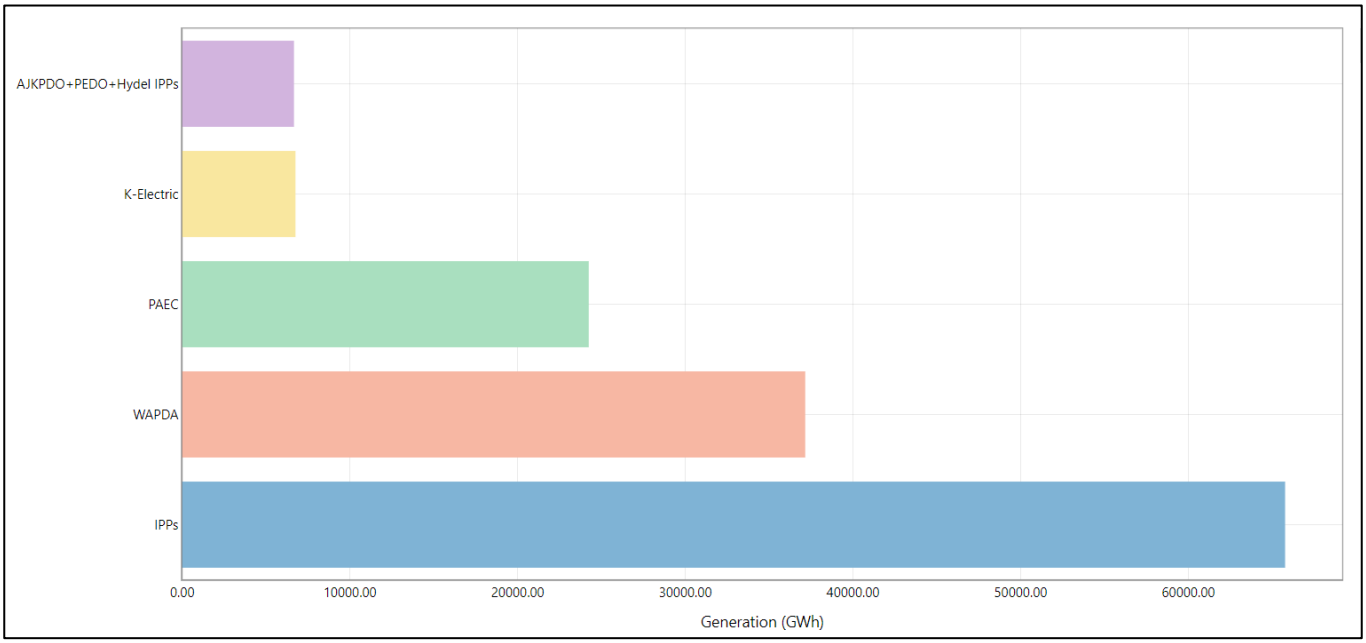


Figure 5.1A. FY2024-25 electricity generation by producer group.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Figure 5.3. Producer groups are institutional/ownership categories and are not fuel categories.

For the complete FY2024-25 year, the Energy Yearbook reports electricity consumption of 113,139 GWh. Domestic use was 57,455 GWh, industrial 29,181 GWh, commercial 9,721 GWh and agriculture 5,882 GWh. This annual profile provides a more complete denominator for year-on-year demand analysis, while the July-March FY2026 figures below remain the more current partial-year signal (HDIP, 2026).

This sectoral structure matters for resource selection. Household demand is strongly affected by tariff affordability and distributed solar; industrial users value reliability and power quality; agriculture is closely coupled to groundwater pumping and therefore to the water-energy nexus. Later chapters use the available monthly and selected hourly evidence, while a fully auditable chronological model still requires complete hourly load data before the value of firming, storage or demand response can be quantified.

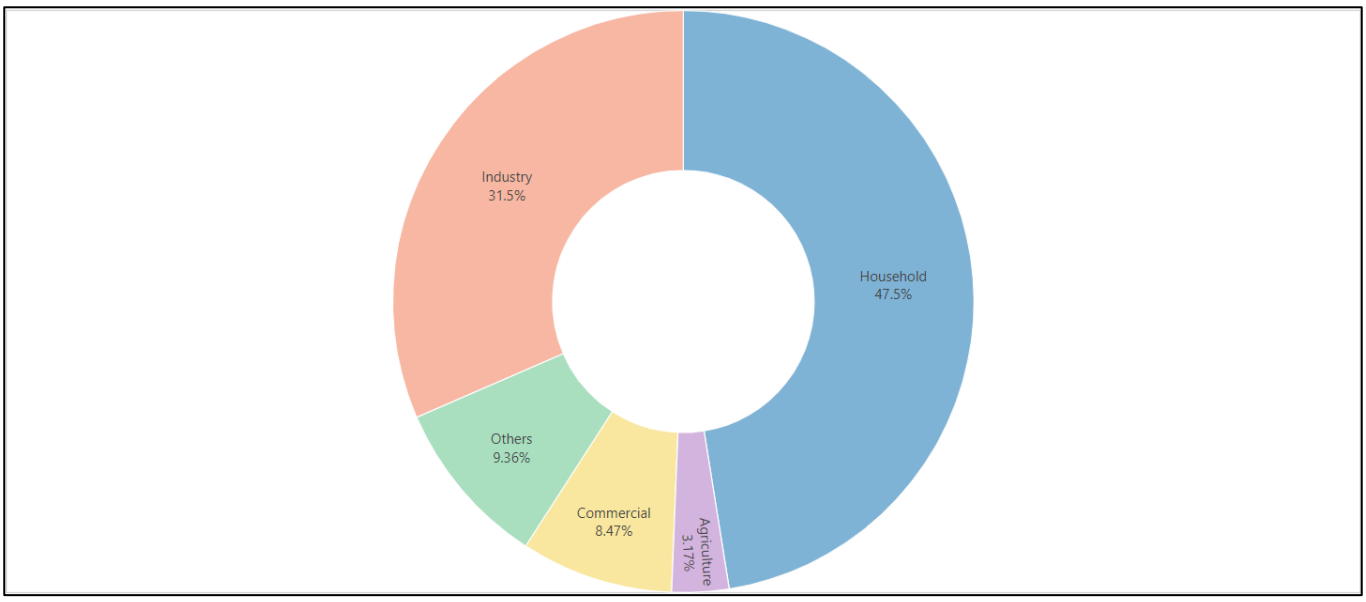


Figure 5.2. Pakistan electricity consumption by sector, Jul-Mar FY2026.

Source: Government of Pakistan (2026), Table 14.3.

The Yearbook public-utilities electricity balance also reports FY2024-25 net supply of 148,458 GWh and T&D losses of 35,316 GWh, or 23.8% of net supply. This must not be treated as the same metric as the 10.87% CY2026 units-received/sold loss forecast used later in the economics calibration; the two values have different periods, denominators and system boundaries. Avoided-loss economics therefore require boundary reconciliation before monetization (HDIP, 2026; NEPRA, 2026).

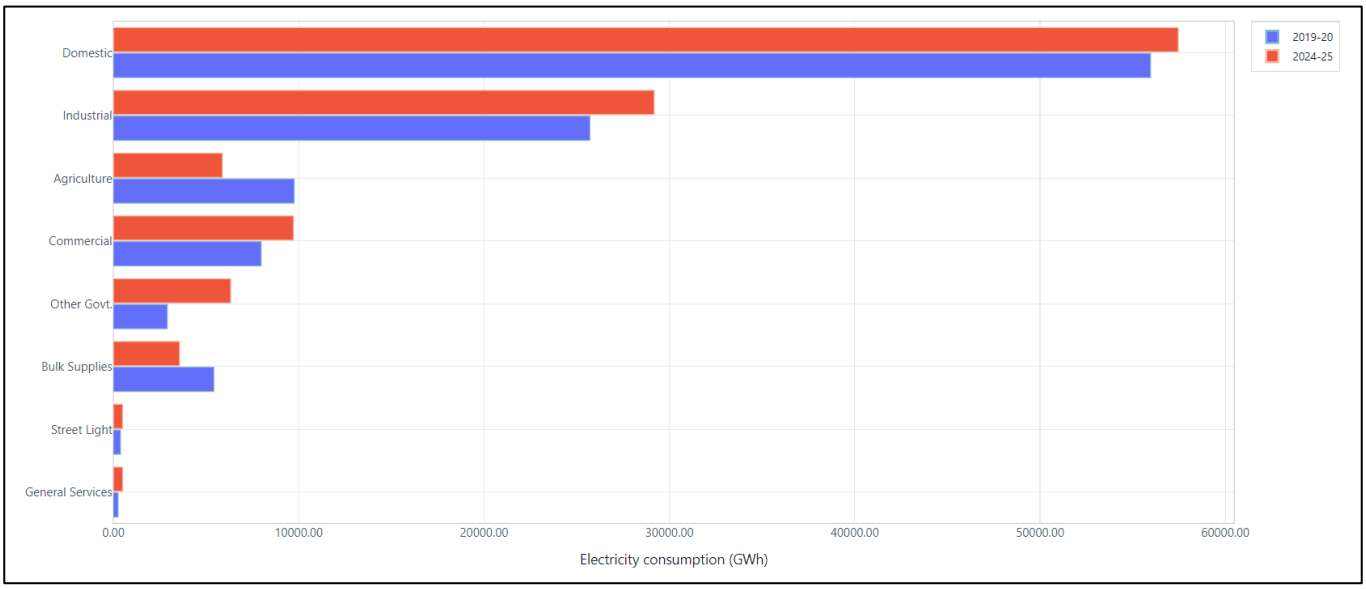


Figure 5.2A. Complete-year electricity consumption by sector, 2019-20 versus FY2024-25.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Figure 5.4 and Table 5.9. Sector-row sums differ from the published annual totals by 1 GWh because of source rounding.

The complete-year comparison shows that total public-utilities electricity consumption rose only about 4.4% between 2019-20 and FY2024-25, but the sector composition changed unevenly. Domestic use rose about 2.7%, industrial use about 13.5% and commercial use about 21.9%, while agricultural grid consumption fell about 39.7%. The changes are descriptive rather than causal: distributed solar, tariff response, economic activity, pumping practices, metering and category reclassification can all affect the observed sector totals.

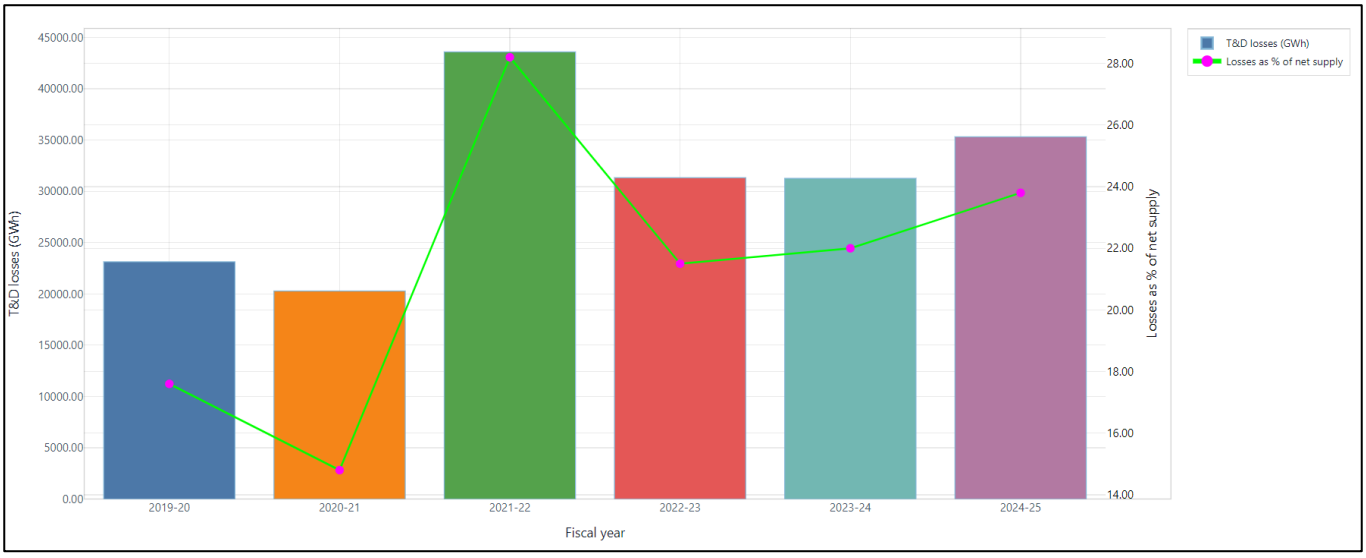


Figure 5.2B. Public-utilities transmission and distribution losses, 2019-20 to FY2024-25.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Table 5.9. The loss percentage uses the Yearbook public-utilities net-supply boundary and should not be equated directly with later regulatory loss metrics using different denominators.

The Yearbook series reinforces the efficiency argument. Reported T&D losses were 35,316 GWh in FY2024-25, equivalent to 23.8% of net supply, compared with 17.6% in 2019-20; the series also contains a 28.2% high in 2021-22. Even without monetizing avoided losses here, the scale is large enough that network efficiency, theft/loss reduction, metering, demand management and transmission/distribution reinforcement must be assessed as supply-equivalent interventions alongside new generation.

5.3 Renewable capacity trajectory

IRENA's standardized capacity series shows that Pakistan's renewable power capacity expanded substantially over 2016-2025, with hydropower remaining the largest component and solar becoming the fastest-growing component in the series. The IRENA series is useful for cross-country comparison because it applies a common capacity definition, but the national and IRENA classifications should not be mixed without checking treatment of distributed and off-grid capacity.

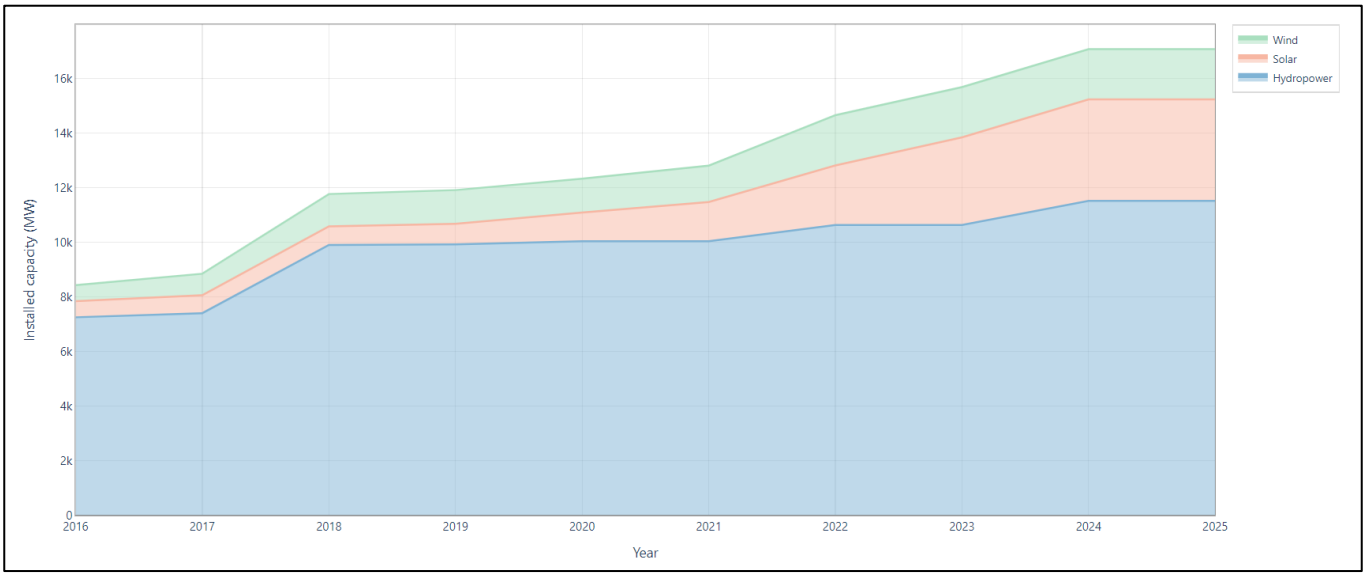


Figure 5.3. Pakistan renewable power capacity by major technology, 2016-2025.

Source: IRENA (2026), Renewable Capacity Statistics 2026. Values represent maximum net generating capacity installed and connected according to IRENA definitions.

5.4 Private generation and the changing project pipeline

The Pakistan Economic Survey reports that PPIB had facilitated 90 operational IPPs with a cumulative capacity of roughly 20.8 GW during the review period, including wind, solar, bagasse, Thar coal, hydro, gas/RLNG, imported coal and RFO projects. The current PPIB pipeline described in the Survey is more heavily weighted toward hydro and other renewables than the historical operating fleet. These project lists should be reconciled against the current IGCEP/Integrated System Plan and NEPRA records before they are used for long-term scenario modelling.

The Year Book 2023-24 provides an important historical checkpoint before the present 2026 baseline. As of May 2024, net-metering installations had reached 2,187 MW. PPIB reported 100 commissioned IPPs totaling 24,958 MW, together with the 4,000 MW +660 kV Matiari-Lahore HVDC transmission project; the generation portfolio was described as 61% of national-grid capacity and as having attracted more than US$33 billion of foreign direct investment. These values are retained as period-specific administrative evidence and are not mechanically merged with later capacity totals because project status, institutional coverage and accounting definitions change over time (Ministry of Energy (Power Division), 2024).

The Pakistan Energy Yearbook 2024-25 now supplies the intervening full-year statistical bridge. It is used for national energy balances, fuel imports, electricity generation/consumption and selected plant cross-checks, while the 2023-24 Power Division Year Book remains the administrative and policy checkpoint. Keeping these functions separate avoids

treating different institutional products as interchangeable datasets (HDIP, 2026; Ministry of Energy (Power Division), 2024).

The presence of a large installed base does not remove the need for system optimization. Capacity payments, dispatch order, fuel availability, transmission constraints, distributed solar, demand growth and plant efficiency all influence the economic value of the fleet. NEPRA's 2025 State of Industry Report and current data repository will therefore be a core acquisition source in the subsequent analysis.

5.5 First baseline interpretation

The 2023-24 Year Book also documents the institutional linkage between generation expansion, transmission planning, distribution modernization and demand-side efficiency. It records the IGCEP/TSEP planning interface, the role of PPIB in private generation and transmission development, and distribution-side measures including advanced metering, loss reduction and asset monitoring. This reinforces the central system argument of this synthesis: adding resource capacity is not sufficient unless metering, networks, dispatch, institutions and demand-side capability can convert that capacity into reliable and affordable service (Ministry of Energy (Power Division), 2024).

6. Pakistan Water-Energy Nexus

6.1 Water availability and stress

The Pakistan Economic Survey 2025-26 reports groundwater contribution of approximately 50 MAF annually, average annual river water receipts of 138.4 MAF, and combined live storage of approximately 13.44 MAF in Tarbela, Mangla and Chashma. It also states that per-capita annual water availability has fallen below 1,000 cubic metres and that groundwater extraction in the Indus Basin increasingly exceeds natural recharge. These figures make water a first-order energy-planning constraint rather than a secondary environmental metric (Government of Pakistan, 2026, Agriculture section 2.2-d).

Table 6.1. Selected national water indicators relevant to energy planning.

Indicator	Reported value	Energy-planning relevance
Groundwater contribution	~50 MAF/year	Major supplementary source; extraction increasingly exceeds recharge in the Indus Basin.
Average annual river water received	138.4 MAF/year	Western and eastern rivers as reported in the Survey.
Live storage: Tarbela + Mangla + Chashma	~13.44 MAF	National storage baseline in the Survey.
Per-capita annual water availability	<1,000 m^3/person/year	Threshold statement, not an exact point estimate.
Main/branch canal network	~64,000 km	Irrigates about 47 million acres according to the Survey.

Source: Government of Pakistan (2026), Pakistan Economic Survey 2025-26, Agriculture 2.2-d Irrigation.

6.2 Why water changes technology ranking

Hydropower depends directly on river flow, head, reservoir operation and competing irrigation requirements. Its energy value is therefore seasonal and system-dependent, even where the technical resource is large. Pumped storage additionally requires suitable topography, reservoirs and an energy source for pumping, but can convert variable renewable surplus into dispatchable electricity.

Thermal power technologies can require substantial cooling water depending on plant type and cooling configuration. Coal and nuclear projects must therefore be evaluated at site level, not only by national resource abundance. Solar PV

and wind generally have lower operational water requirements, but utility-scale solar still has cleaning and site-water considerations in dusty, arid regions.

Geothermal requires special treatment because the produced geofluid is part of the reservoir system and is not necessarily freshwater. Binary plants can transfer heat through a heat exchanger while reinjecting the geothermal fluid. Dry or hybrid cooling can reduce freshwater demand but may change cost and performance. The study will therefore distinguish geothermal geofluid production, reinjection, cooling make-up water and competing freshwater demand rather than combining them into one “water-use” number.

6.3 Proposed Water Compatibility Index

A Water Compatibility Index provides a structured basis for project and technology comparison. It will track water source, withdrawal, consumptive use, salinity and treatment, cooling system, reinjection fraction, competing domestic/agricultural use, local water-stress context, disposal chemistry and, for geothermal, pressure support and induced-seismicity considerations. The index remains semi-quantitative where harmonized project-level water data are unavailable.

6.4 Water-data gaps

The present baseline is sufficient to establish water stress as a central constraint but not yet sufficient to rank technologies quantitatively. Further quantitative ranking requires IRSA/WAPDA flow and storage time series, technology-specific withdrawal and consumption data under comparable cooling assumptions, project EIA water balances, and local groundwater availability and quality for candidate sites.

7. Indigenous Resources, Import Exposure and the Energy-Security Challenge

7.1 Petroleum-group import and foreign-exchange exposure

During July-March FY2026, Pakistan’s petroleum-group imports were about US$11.25 billion, equivalent to 22.2% of total goods imports. The Pakistan Economic Survey reports crude-oil imports of roughly US$4.5 billion and petroleum-product imports of roughly US$4.1 billion. LNG imports declined by 29.7% year on year, but still represented approximately US$1.9 billion of foreign-exchange exposure. Imported LNG is regasified and consumed domestically as RLNG, so a national energy-import assessment should place the LNG import bill alongside crude oil and petroleum products rather than treating RLNG only as a consumption-volume category. The broad petroleum-group comparison below is therefore used for foreign-exchange exposure, while the more detailed product table in the Energy chapter remains useful for petroleum-product composition (Government of Pakistan, 2026, Trade and Payments).

The full FY2024-25 Yearbook provides an annual foreign-exchange bridge to that partial-year FY2026 account. It reports an oil import bill of about US$11.4 billion and LNG imports of 8.74091 MTOE valued at about US$3.371 billion. These are not added mechanically to the Jul-Mar FY2026 petroleum-group totals because the periods and accounting scopes differ; instead, they establish the preceding full-year exposure against which the later decline in LNG imports can be interpreted (HDIP, 2026).

Historical planning context is provided by the Pakistan Energy Outlook Report 2021-2030. Using data available through 2020, it projected oil and POL primary supply of about 24.16 million tonnes by 2030, including about 22.16 million tonnes of crude-oil and POL imports, while indigenous crude processed through refineries declined. These values are model outputs rather than current observations; they are retained to test whether the earlier official diagnosis of persistent petroleum import exposure remains directionally valid against the newer FY2026 evidence (Ministry of Planning, Development & Special Initiatives, 2022).

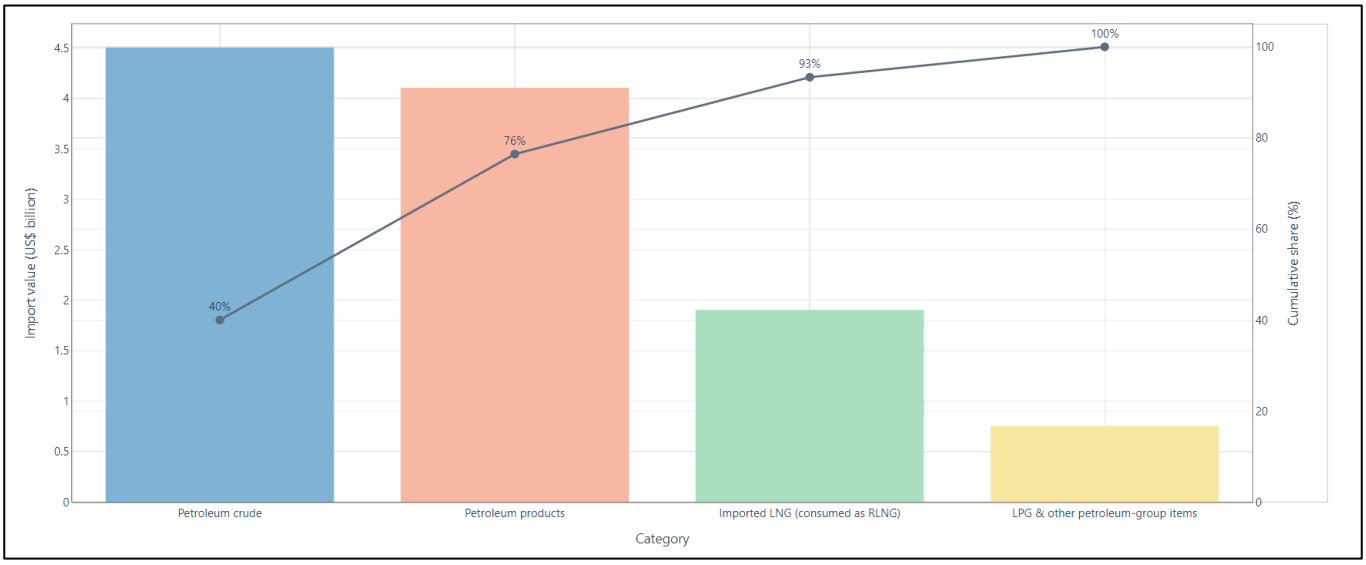


Figure 7.1. Pakistan petroleum-group import bill by major fuel, Jul-Mar FY2026.

Source: Government of Pakistan (2026), Pakistan Economic Survey 2025-26, Trade and Payments, Fig. 8.10 and accompanying text. Values are rounded; LNG is imported as LNG and consumed after regasification as RLNG. LPG/other is the approximate residual of the reported petroleum-group total.

7.2 Natural gas and RLNG

The Economic Survey reports total gas consumption of about 2,929 MMCFD during July-March FY2026, comprising about 2,316 MMCFD of indigenous gas and 613 MMCFD of RLNG across the listed sectors. The power sector consumed 924 MMCFD, of which 405 MMCFD was RLNG; general industry consumed 382 MMCFD, of which 122 MMCFD was RLNG. Domestic and fertilizer demand remained overwhelmingly supplied by indigenous gas in the reported period (Government of Pakistan, 2026, Table 14.9). This 613 MMCFD RLNG figure is a consumption rate, whereas Figure 7.1 captures the separate foreign-exchange cost of importing LNG; the two measures should not be conflated.

The FY2024-25 Yearbook adds an important qualification to a simple 'gas depletion' narrative. Average natural-gas production fell 7.52% year on year to about 2,890 MMCFD, but proved gas reserves were reported to have risen from 18.47 Tcf to 23.31 Tcf by 30 June 2025, largely because of discoveries and appraisal. The policy and economics implication is that reserves, annual production and deliverability are different variables: reserve growth does not by itself remove near-term supply constraints or the value of LNG/RLNG flexibility (HDIP, 2026).

This composition demonstrates why gas policy cannot be reduced to a single import-dependence percentage. The security value of replacing gas-fired electricity depends on which gas molecule is being displaced, what alternate sector could use it, and the capacity and flexibility value of the power plant being replaced. The economics model will therefore test avoided imported LNG separately from the opportunity cost of indigenous gas.

The same Outlook projected sectoral gas consumption of 1,337 Bcf and an LNG import requirement of roughly 1,900 MMCFD by 2030 under declining indigenous production. It also identified LNG infrastructure and terminal management, captive-power migration to the grid and north-south gas transport as planning issues. These are historical planning assumptions, not current commitments, but they provide a useful stress case against which the FY2026 indigenous-gas and RLNG split can be assessed (Ministry of Planning, Development & Special Initiatives, 2022).

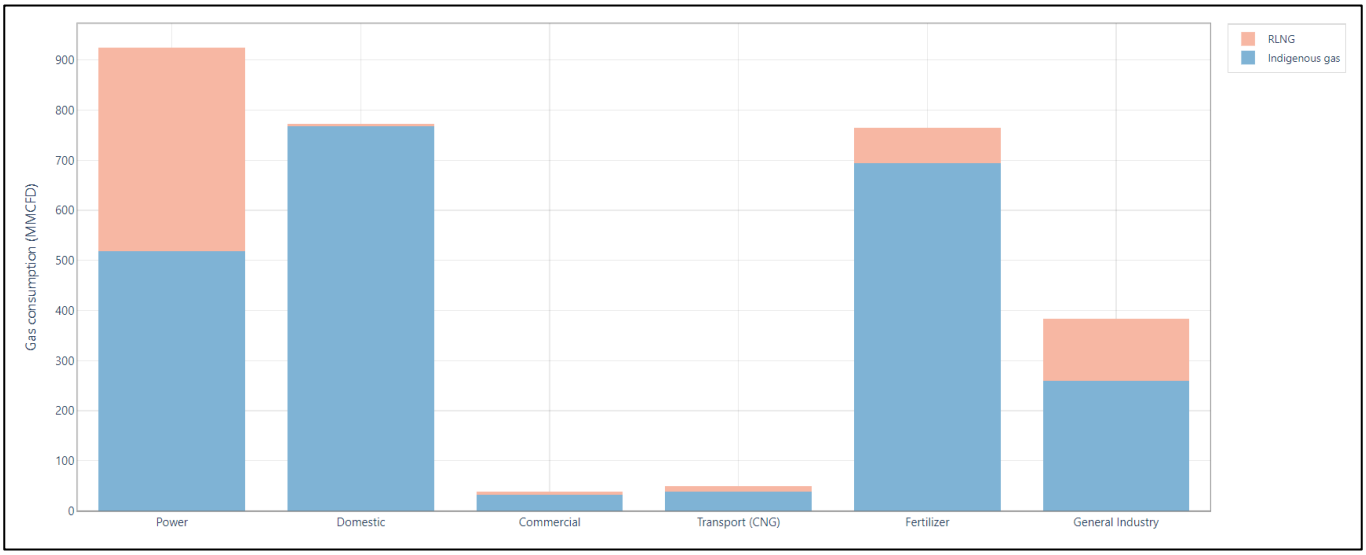


Figure 7.2. Indigenous gas and RLNG consumption by sector, Jul-Mar FY2026.

Source: Government of Pakistan (2026), Table 14.9.

Upstream activity, production deliverability and import exposure

The Yearbook allows the upstream-security argument to be tested more carefully than a simple depletion statement. Exploration and appraisal/development drilling continued through FY2024-25, including 28 exploratory wells and 30 appraisal/development wells, while the Yearbook reports 21 discoveries for the year. Yet domestic crude-oil and natural-gas production both continued below their 2019-20 levels. This means that drilling effort and discoveries should be judged not only by counts but by reserve quality, commerciality, development lead time and the rate at which new volumes translate into sustainable deliverability.

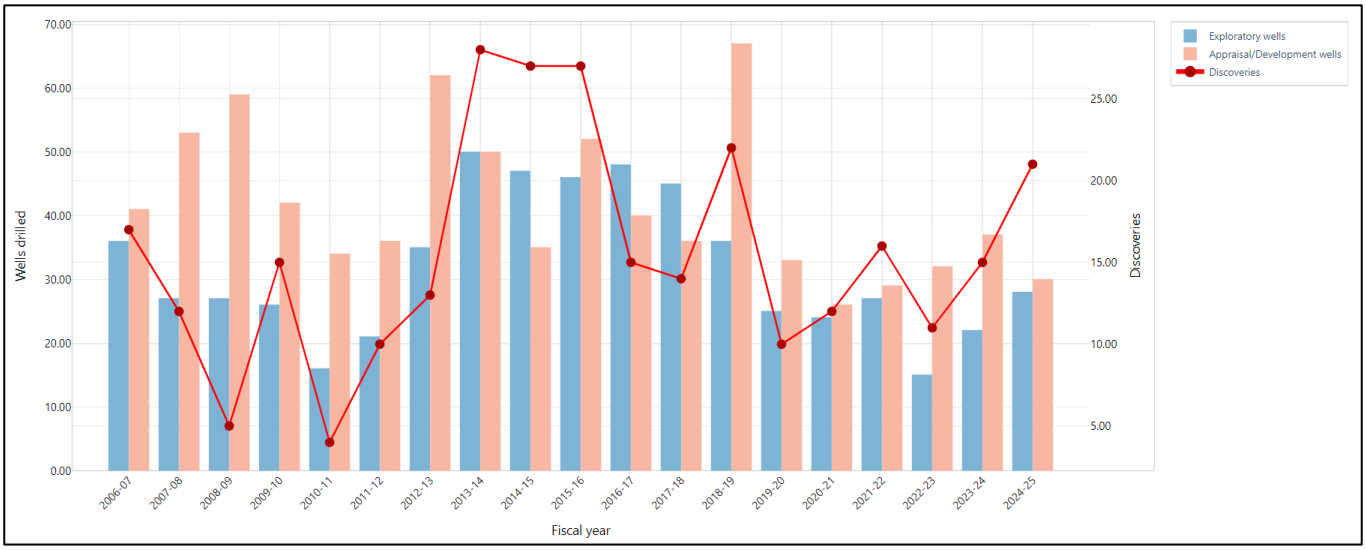


Figure 7.2A. Hydrocarbon drilling activity and discoveries, 2006-07 to FY2024-25.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Figure 6.1. Exploratory and appraisal/development well counts are published annual values; discovery counts are reproduced from the Yearbook figure and are best treated as chart-level annual counts rather than reserve additions.



Figure 7.2B. Domestic crude-oil and natural-gas production trend, indexed to 2019-20 = 100.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Tables 2.2 and 3.2/3.3. Indexing is a study calculation used only to compare trend direction across different physical units.

From 2019-20 to FY2024-25, average crude-oil production fell from about 76,739 to 62,459 bbl/day (roughly 18.6%), while average natural-gas production fell from about 3,597 to 2,890 MMcf/d (roughly 19.7%). The reserve picture is more nuanced: oil reserves declined from about 243 to 240 million barrels, whereas reported gas reserves increased from 18.47 to 23.31 Tcf following discoveries and appraisal/re-evaluation. The defensible conclusion is therefore not that reserve additions are absent, but that new reserve recognition has not yet reversed the decline in domestic production deliverability.

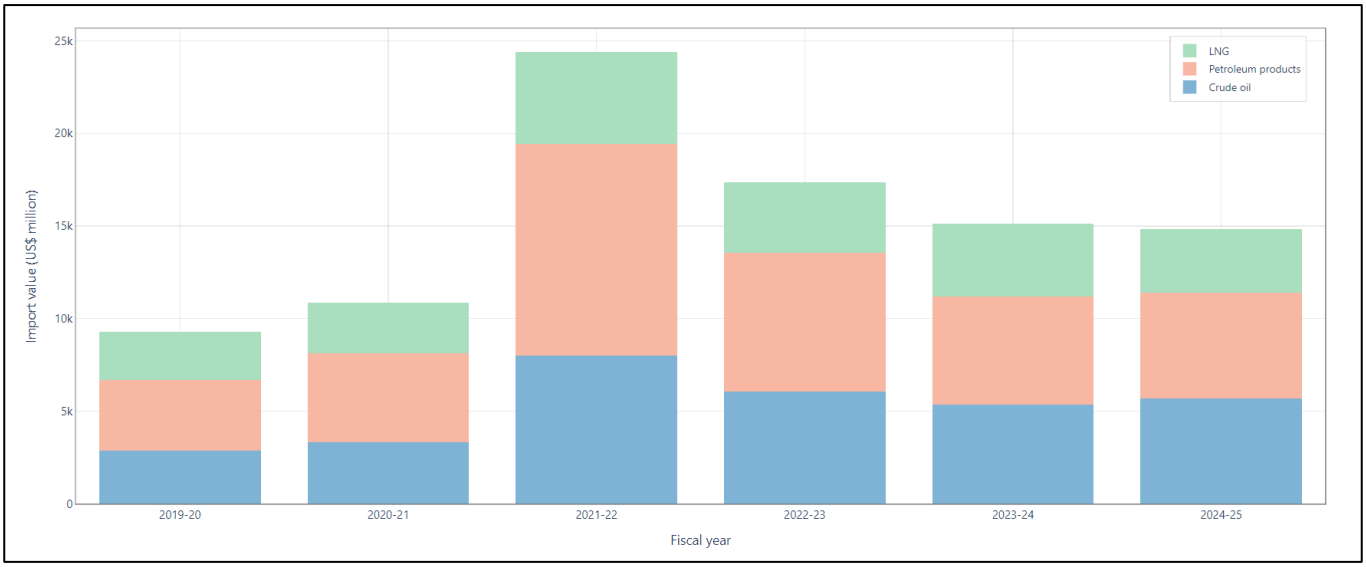


Figure 7.2C. Selected hydrocarbon import-cost exposure: crude oil, petroleum products and LNG, 2019-20 to FY2024-25.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25, Tables 2.11, 2.12 and 3.8. This chart combines crude-oil, petroleum-product and LNG import values only; it is not the complete national energy-import bill.

The import-cost history also shows why energy security is a macroeconomic exposure as well as a resource question. The selected oil-plus-LNG import values peaked during the 2021-22 price shock and remained material in FY2024-25. For policy analysis, the implication is to reduce avoidable exposure through domestic resource productivity, efficiency and economically defensible indigenous/renewable supply, while retaining enough diversified import access and system flexibility to manage domestic resource and weather variability.

7.3 Indigenous coal: security value and constraint set

The Pakistan Economic Survey describes the Thar coal resource at about 175 billion tonnes and reports five PPIB-facilitated Thar coal IPPs totaling 3,300 MW. During July-March FY2026, the power sector accounted for about 59.6% of reported coal consumption, brick kilns about 20.8%, and cement/other industries about 19.6%. This establishes coal as a material indigenous resource, but resource abundance is not sufficient to establish optimal future use.

The Energy Yearbook provides a more specific FY2024-25 supply-and-import balance: measured coal reserves of 7,775.5 million tonnes, domestic production of 18.75 million tonnes, imports of 6.98 million tonnes, total consumption of 25.73 million tonnes and a coal import bill of about PKR 203 billion. It reports that 51% of imported coal was used by the power sector and 49% by cement and other industries. These values strengthen the import-substitution test but do not establish the economic case for new coal capacity without mine, plant, water, environmental and financing analysis (HDIP, 2026).

The coal analysis therefore tests mine-mouth cost, transport, plant efficiency, water requirement, local air pollutants, carbon intensity, ash and waste, financing conditions, remaining plant life and the system value of firm generation. The analysis also tests whether some existing imported-coal assets can technically and economically convert to Thar coal. Recommendations remain conditional where these dimensions cannot be quantified consistently.

The Outlook likewise projected coal use rising toward 50 million tonnes by 2030 and explicitly examined substitution of imported coal with Thar and other local coal. The present synthesis retains that result as a published energy-security hypothesis rather than as a validated forecast. Later plant-level evidence in Chapter 34 is used to test observed utilization and payment intensity before drawing any conclusion about the economic case for further indigenous-coal expansion (Ministry of Planning, Development & Special Initiatives, 2022).

7.4 Renewable and hydro resources

Pakistan’s renewable and hydropower base is already material, and the standardized IRENA series confirms significant growth in solar capacity over the past decade. A 2020 World Bank planning study found that a major expansion of solar and wind to at least 30% of total capacity by 2030 was least-cost in its model and estimated potential system savings of about US$5 billion over twenty years, primarily from reduced fuel consumption. These are model results from a 2020 study, not present-day observations, and is re-tested against current costs, grid conditions and the 2025-35 planning framework before being adopted as current recommendations.

7.5 Geothermal: from prospectivity to bankability

Pakistan has documented geothermal manifestations and several tectonic settings that justify systematic assessment, but the evidence base does not yet support a national bankable “X GW” resource claim. The current dataset therefore begins at the measurement scale rather than at a national potential number.

The open-access Zindapir Anticlinorium study provides one of the strongest recent integrated datasets. Reported hot-spring temperatures are about 50.3°C at Zindapir, around 40°C at Jaffarabad and 58°C at Gulki, with high dissolved-solids concentrations and variable major-ion chemistry. Magnetic spectral analysis in ten blocks yielded geothermal-gradient estimates of roughly 20.7-23.3°C/km and heat-flow estimates of about 59-66 mW/m². In Zindapir-01, the study reports formation-level average temperatures of about 38°C in the Pab Sandstone, 62°C in the Lower Goru Formation and 100°C in the Chiltan Limestone, while its broader property model predicts higher temperatures laterally in parts of the study area (Rasheed et al., 2026).

The most important methodological point is that prospectivity is not a commercial reserve. Hot springs, heat-flow anomalies and modelled reservoir properties justify ranking and further field work; they do not by themselves establish sustainable flow rate, recoverable thermal power, drilling success probability or project economics. A staged workflow is therefore required: national desktop inventory, prospect ranking, field geochemistry and geophysics, confirmation drilling, reservoir testing, then direct-use or modular power pilots at confirmed sites.

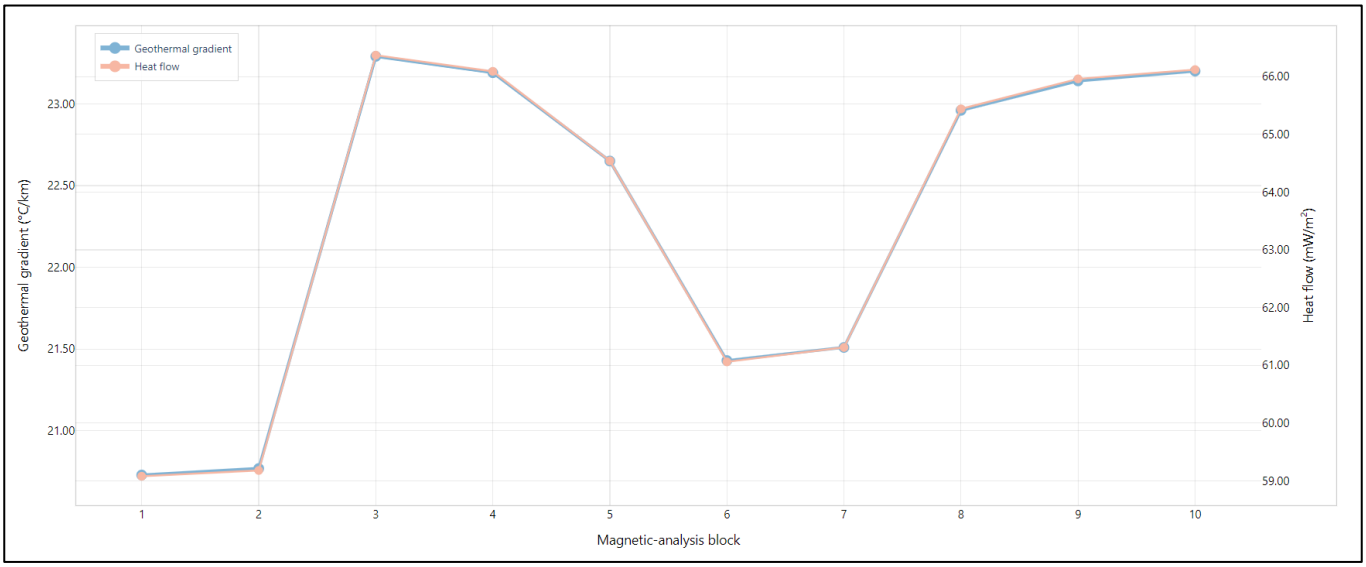


Figure 7.3. Zindapir Anticlinorium geothermal-gradient and heat-flow estimates by magnetic-analysis block.
Source: Rasheed et al. (2026), Table 3. Values are estimates from magnetic spectral analysis, not direct downhole heat-flow measurements.

7.6 Geothermal financing as an energy-security test case

The upstream-risk structure of geothermal makes it an ideal test of the synthesis's investor-user framework. World Bank experience shows that exploratory drilling can absorb substantial capital before commercial resource confirmation. Türkiye's geothermal programme combined a risk-sharing mechanism for resource validation with long-term financing, while Indonesia developed facilities designed to share exploration losses and then crowd in larger private investment after resource confirmation. These models suggest that Pakistan should test a public/concessional exploration-risk facility as a hypothesis rather than requiring private developers to carry the entire wildcat risk from the outset.

7.7 First integrated energy-security synthesis

The baseline analysis integrated conclusion:
The evidence available so far does not support a single "game changer" resource. Pakistan's strongest path is more likely to be a portfolio in which low-cost variable energy, firm indigenous resources, storage/flexibility, grid reinforcement, efficiency and selective fuel substitution are optimized together. The relative shares cannot yet be fixed because project-level economics, hydro seasonality, water-use data, transmission constraints and several resource datasets are still incomplete.

This conclusion is intentionally provisional. It is the starting hypothesis to be challenged by the resource-specific chapters and the common economics model. A technology will be preferred only where its full delivered-system value, water compatibility, reliability contribution and project bankability outperform the relevant alternatives.

7.8 Residual evidence requirements

Table 7.1. Residual evidence requirements and their analytical purpose.

Priority	Dataset / source family	Purpose
1	NEPRA State of Industry 2025 data repository and operational-plant performance	Reconstruct generation, utilization, losses, outages and delivered sector performance.
2	NEPRA tariff determinations and PPIB/WAPDA/World Bank/ADB project documents	Build project-level CAPEX, EPC, O&M, tariff, financing and infrastructure-cost database.

Priority	Dataset / source family	Purpose
3	IRSA/WAPDA hydrology and reservoir operations	Build monthly/annual flow, storage, hydro-generation and water-allocation series.
4	World Bank/ESMAP solar and wind resource-zone data plus transmission proximity	Develop spatial suitability and delivered-cost mapping.
5	National geothermal inventory including hot springs, corrected well BHT, gradients, faults and geochemistry	Rank 10-20 prospects for field confirmation.
6	Hourly/monthly demand and renewable generation data	Quantify complementarity, curtailment, storage and firm-capacity value.
7	Technology-specific water and lifecycle/environmental metrics	Complete water-energy and sustainability comparisons.

PART IV - RESOURCE-SPECIFIC SYNTHESIS

8. Geothermal and Hydrothermal Energy

8.1 Purpose, terminology and decision question

This chapter treats hydrothermal geothermal systems as naturally occurring subsurface heat associated with water or steam reservoirs. It is distinct from hydropower, which is addressed separately. The decision question is not whether Pakistan has thermal manifestations; published evidence already establishes that it does. The decision question is whether particular manifestations can be converted into sustainable, technically producible and economically bankable heat or electricity projects under Pakistan-specific water, grid, drilling and financing conditions.

The evidence hierarchy used here is deliberately staged: surface manifestation and tectonic setting indicate prospectivity; geochemistry and geophysics constrain the conceptual system; wells and flow tests establish reservoir performance; and only sustained production/injection plus engineering and finance establish a bankable resource. A hot spring, high gradient or favorable structural setting must therefore never be translated directly into national megawatts.

8.2 Global context: geothermal is a firm resource, but not a low-risk resource

IRENA reports that about 320 MW of new geothermal power was commissioned in 2024, taking global installed capacity to almost 15.4 GW. For projects commissioned in 2024, the global weighted-average levelized cost of electricity (LCOE) was USD 0.060/kWh, weighted total installed cost was USD 4,015/kW, and weighted average capacity factor was 88%. Country outcomes varied sharply: Türkiye recorded about USD 0.033/kWh with total installed cost of USD 1,217/kW and a 91% capacity factor; New Zealand recorded about USD 0.042/kWh, USD 2,987/kW and 91%; Indonesia recorded about USD 0.090/kWh while total installed cost exceeded USD 6,000/kW. (IRENA, 2025)

These values make two points that are central to this synthesis. First, geothermal can provide high-utilization electricity that complements variable solar and wind. Second, the cost range is wide because subsurface conditions, drilling performance, project size, supply chains, financing and development maturity are highly site-specific. A global average is therefore an analogue, not a Pakistan project assumption.

The IEA similarly describes geothermal as a source of around-the-clock electricity, heat and storage, and reports global geothermal utilization above 75% in 2023. Its 2024 scenario analysis suggests that, if technology and costs improve substantially, geothermal could meet up to 15% of global electricity-demand growth to 2050, corresponding to as much as 800 GW. Those numbers are conditional scenario results and are used here only as strategic context. (IEA, 2024)

8.3 Pakistan-wide evidence: prospectivity is geographically broad but unevenly characterized

Published Pakistani literature has long associated geothermal manifestations with major tectonic and volcanic domains, including the Chagai volcanic arc, the northern collision zone and major sutures/thrusts, Sindh hot springs, thermal seepages around the syntaxial bend, and the Hamun-e-Mushkhel graben. The accessible 2016 survey also identifies numerous hot springs and mud-volcano localities and argues that moderate-temperature resources may be suited to binary-cycle generation (Kanwal, S. et al., 2020; Younas et al., 2016).

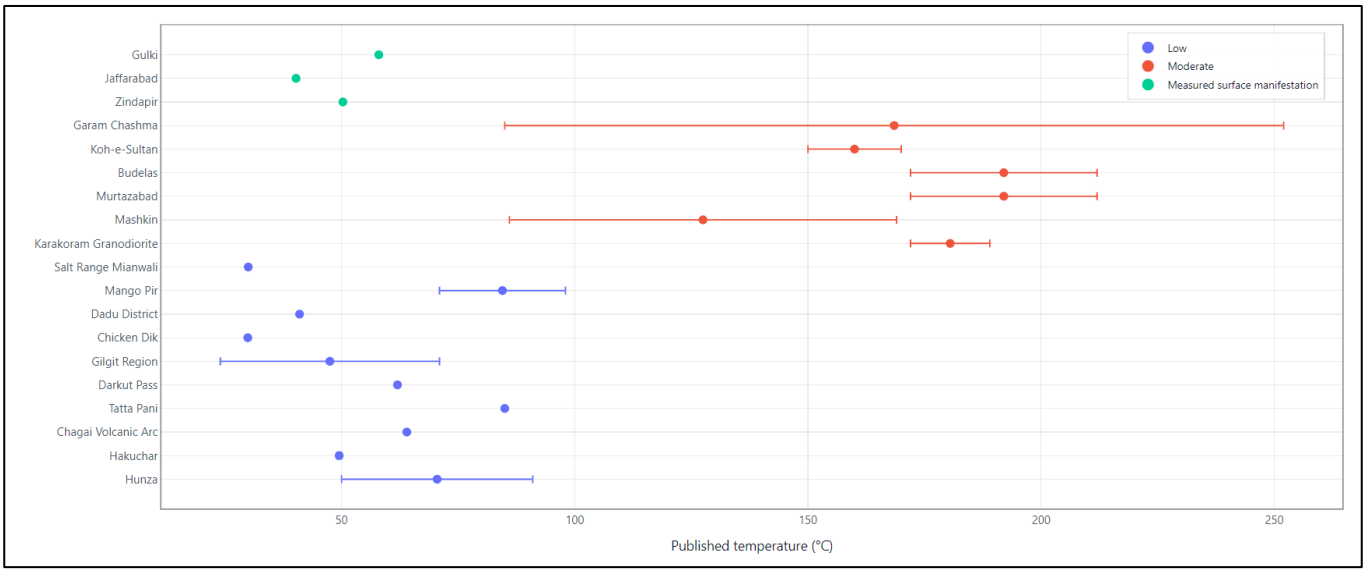


Figure 8.1. Published temperature ranges for selected geothermal manifestations in Pakistan.

Sources: secondary published compilation (Kanwal et al., 2020) and open-access Zindapir study (Rasheed et al., 2026). Values are screening evidence; they are not a reserve or plant-capacity estimate.

For geothermal project screening, the companion evidence database contains normalized global 2024 geothermal benchmarks of about USD 4,015/kW installed cost, 88% capacity factor and USD 0.060/kWh LCOE. It also retains the World Bank Türkiye exploration-risk facility as a financing analogue, while unsupported Pakistan project inputs remain blank rather than being inferred.

8.4 Zindapir Anticlinorium: the strongest open-access integrated Pakistan case

Rasheed et al. integrate remote sensing, hot-spring geochemistry, gravity, magnetic data, seismic interpretation and petrophysics in the Eastern Sulaiman Fold and Thrust Belt. Surface hot springs at Zindapir, Jaffarabad and Gulki were reported at approximately 50.3 °C, 40.1-40.4 °C and 58 °C, respectively. The authors interpret sodium-rich chemistry as evidence for deep circulation and distinguish immature from partially equilibrated thermal waters. (Rasheed et al., 2026)

Magnetic spectral analysis in the study gives Curie point depths of roughly 24.90-27.98 km, geothermal gradients of about 20.73-23.29 °C/km, and heat-flow estimates of about 59.08-66.37 mW/m2. The Zindapir-01 well is reported to show a temperature increase from near-surface values to about 155 °C at 4,500 m total depth. The selected Pab Sandstone, Lower Goru Formation and Chiltan Limestone intervals have reported average temperatures of 38.01 °C, 62.28 °C and 99.73 °C respectively, with strongly variable porosity and permeability. (Rasheed et al., 2026)

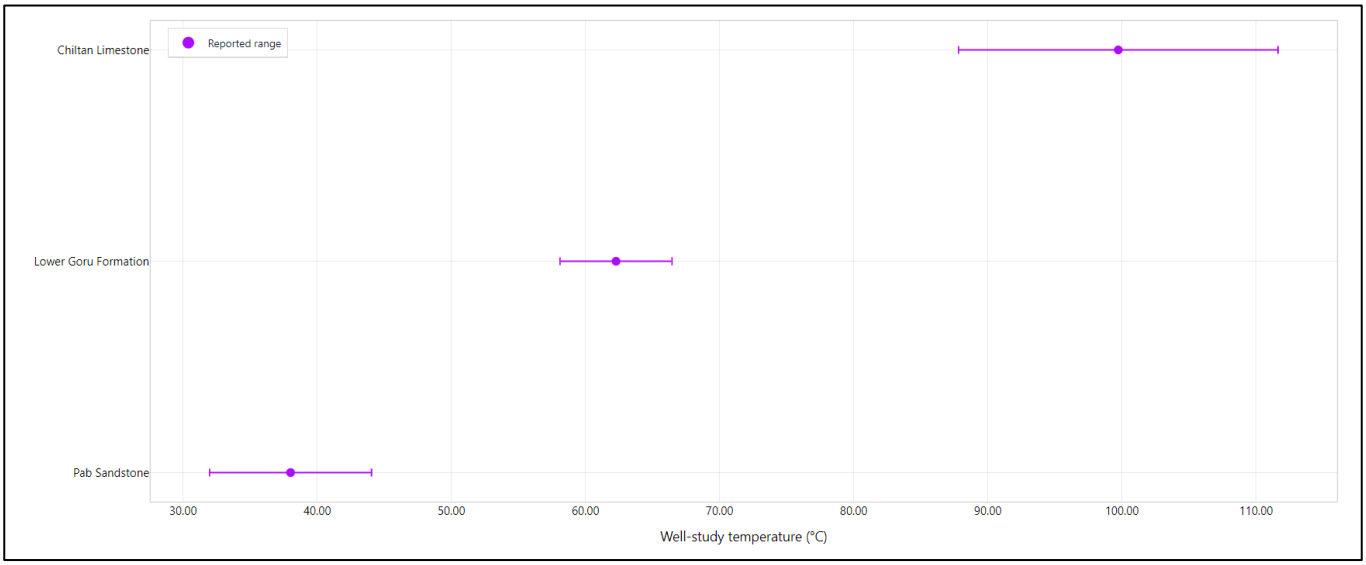


Figure 8.2. Zindapir-01 published formation temperature ranges.

Source: Rasheed et al. (2026), Table 4. These are petrophysical/well-study results, not demonstrated production temperatures or sustainable flow tests.

The strength of this case is the convergence of several independent evidence streams. Its limitation is equally important: the published study establishes prospectivity and candidate reservoir intervals, but does not provide the sustained production-rate, injectivity, pressure-decline, chemistry-management and long-term reservoir-performance evidence required to size a commercial plant.

8.5 Resource classification for this synthesis

Table 8.1. Geothermal evidence classification adopted for the Pakistan synthesis.

Evidence level	Minimum evidence	Permitted conclusion
Level 1 - Manifestation	Hot spring, mud volcano, thermal seepage, anomalous land-surface temperature	Prospect indication only
Level 2 - Conceptual system	Geology + faults + geochemistry + geophysics + temperature-depth evidence	Exploration target
Level 3 - Tested resource	Confirmation well(s), temperature, flow, pressure, chemistry, injectivity	Pre-feasibility resource
Level 4 - Demonstrated reservoir	Repeatable production/injection tests and reservoir model	Engineering design basis
Level 5 - Bankable project	Reservoir + EPC + grid/heat offtake + permits + finance + risk allocation	Investment decision

8.6 Technology matching: direct heat, binary power, flash systems and next-generation geothermal

The most immediate geothermal opportunity need not be electricity. Direct-use heat can exploit lower-temperature resources for applications such as space heating in cold regions, greenhouse/agricultural heat, food drying, aquaculture, process heat and appropriately managed thermal tourism. This route can avoid thermodynamic conversion losses and may become economic at temperatures that are unattractive for electricity generation.

For medium-temperature hydrothermal resources, binary/organic Rankine cycle (ORC) systems are the principal screening technology because the geothermal brine transfers heat through a heat exchanger to a secondary working fluid. Flash-steam development requires higher-temperature fluid and an adequate mass flow, while dry-steam resources are uncommon. Enhanced geothermal systems (EGS) and closed-loop systems expand the future resource

envelope, but they remain a technology-development and cost-reduction pathway rather than a near-term assumption for Pakistan. (IEA, 2024)

A key advantage for Pakistan is the overlap with petroleum-sector capability. The IEA estimates that up to 80% of geothermal investment can involve skills and capabilities common to oil and gas, including subsurface characterization, drilling, completions, fluid-flow management and large-project execution. This creates a plausible path for redeploying national petroleum expertise, but it does not remove geothermal resource risk. (IEA, 2024)

8.7 Water compatibility and reservoir management

Pakistan's water stress changes the preferred geothermal configuration. The synthesis therefore favors closed-loop binary surface plants where technically appropriate, reinjection of produced geothermal fluid, and dry or hybrid cooling where freshwater competition is material. These design choices must be evaluated at site level because air cooling can impose efficiency and cost penalties in hot climates, while reinjection behavior depends on reservoir permeability, pressure support and fluid chemistry.

The World Bank notes that groundwater supplies about 90% of rural domestic water, roughly 70% of domestic water nationally and more than half of agricultural water in Pakistan. The energy study therefore treats freshwater use as an economic and social constraint, not merely as an environmental reporting item. (World Bank, 2021)

8.8 Exploration risk and the case for staged public-private de-risking

Geothermal economics are unusually sensitive to the stage at which private capital is asked to enter. Exploratory drilling may consume large amounts of capital before commercial flow is confirmed. The World Bank's Global Geothermal Development Plan was explicitly designed around this upstream risk, and the Türkiye Geothermal Development Project provides a practical analogue. (World Bank, 2020; World Bank, 2016)

The Türkiye Risk Sharing Mechanism was capitalized with USD 38 million. Under the program design, failed exploration wells could receive 60% coverage in less-explored parts of the country and 40% in the more mature Aydin, Denizli and Manisa areas. Later World Bank synthesis describes a typical initial program of three wells and a maximum payout of USD 4 million per drilling project, with success criteria tied to business-plan requirements and well output. (World Bank, 2016; World Bank, 2023)

For Pakistan, this does not imply copying the percentages. It suggests a policy hypothesis: public or concessional capital should focus on the high-information, high-risk resource-validation stage, while long-term private project finance should enter after temperature, flow, injectivity and chemistry are sufficiently constrained. This hypothesis will be tested economically rather than adopted as a policy conclusion.

8.9 Proposed Pakistan geothermal development pathway

1. Build a national open geothermal inventory integrating hot springs, corrected petroleum-well bottom-hole temperatures, geothermal gradients, faults, seismicity, volcanics, water chemistry, gravity/magnetic data and grid/heat-demand proximity.
2. Rank prospects by system type and evidence quality rather than by surface temperature alone.
3. Conduct field geochemistry and geophysics on the highest-ranked prospects and define explicit drilling success criteria.
4. Drill slim holes or confirmation wells where the pre-drill probability and potential value justify the cost.
5. Test flow, pressure response, chemistry and reinjection before sizing an electricity plant.
6. Develop direct-use pilots where useful heat can be monetized before a power project is justified.
7. Build a modular binary-power pilot only at a site where a sustainable medium-temperature resource is demonstrated.
8. Evaluate a Pakistan Geothermal Exploration Risk Facility using transparent cost-sharing, success criteria and independent technical review.

8.10 Geothermal synthesis and development implications

Pakistan has credible geothermal prospectivity but does not yet have a defensible national commercial-resource number. The Zindapir case demonstrates that petroleum-basin data, geophysics, geochemistry and well logs can be integrated into a modern geothermal screening workflow. The next threshold is not another national potential estimate; it is resource validation at a small number of carefully ranked sites. Until sustainable flow and injection are demonstrated, geothermal should be treated as a promising firm-energy and direct-heat option with high information value, not as proven replacement capacity.

9. Hydropower and Pumped Storage

9.1 Decision question: large indigenous resource, but value is hydrology- and system-dependent

This synthesis separates confirmed operating hydropower, identified technical potential and prospective pumped-storage opportunities rather than combining them into one resource number.

The 2022 PPIB Hydropower Resources of Pakistan inventory identifies about 64,000 MW of hydropower resources. The regional distribution is strongly concentrated in Khyber Pakhtunkhwa and Gilgit-Baltistan, followed by Azad Jammu and Kashmir and Punjab. The same inventory reported about 10.85 GW of installed hydropower at that time and described roughly 84% of the identified potential as untapped. These figures are resource-inventory values, not a statement that every identified megawatt is financially, environmentally or grid-feasible.

Table 9.1. PPIB 2022 hydropower resource inventory by region.

Region	Identified potential (MW)	Installed hydro in 2022 (MW)	Developed share (derived)
Khyber Pakhtunkhwa	27,012.81	5,789.22	21.4%
Gilgit-Baltistan	21,162.35	169.35	0.8%
Azad Jammu & Kashmir	8,295.79	2,370.22	28.6%
Punjab	7,316.13	2,524.06	34.5%
Sindh	208.00	0	0%
Balochistan	5.20	0	0%
Total	64,000.28	10,852.85	17.0%

Source: PPIB (2022), Hydropower Resources of Pakistan. Developed shares are derived from the publication's regional identified-potential and installed-capacity figures.

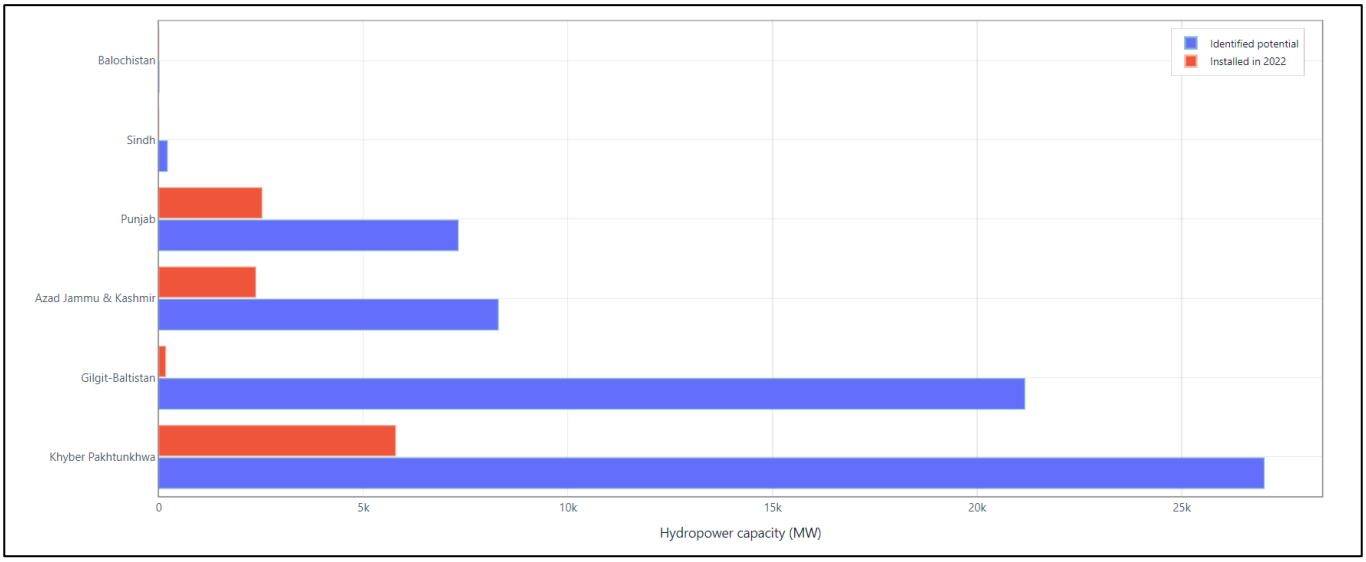


Figure 9.1. Identified hydropower potential and installed hydropower by region in the PPIB 2022 inventory.
Source: PPIB (2022). The figure is a resource-inventory comparison, not a bankable project ranking.

9.2 Existing output: actual 2025 generation shows hydropower as an operating system resource

WAPDA reported 33.12 billion kWh of hydel generation in calendar year 2025 from 22 hydel power stations. Tarbela base units contributed 14.3 billion kWh, Tarbela Fourth Extension 5.6 billion kWh, Ghazi Barotha 6.5 billion kWh, Mangla 3.6 billion kWh, Chashma 0.79 billion kWh, Warsak 0.77 billion kWh and the balance 1.56 billion kWh from other WAPDA hydel stations. WAPDA also reported a hydel tariff of Rs 3.83/kWh for the year. That tariff is useful evidence of the low operating-cost contribution of the existing fleet, but it must not be confused with the full LCOE of a new hydropower project or the delivered retail tariff.

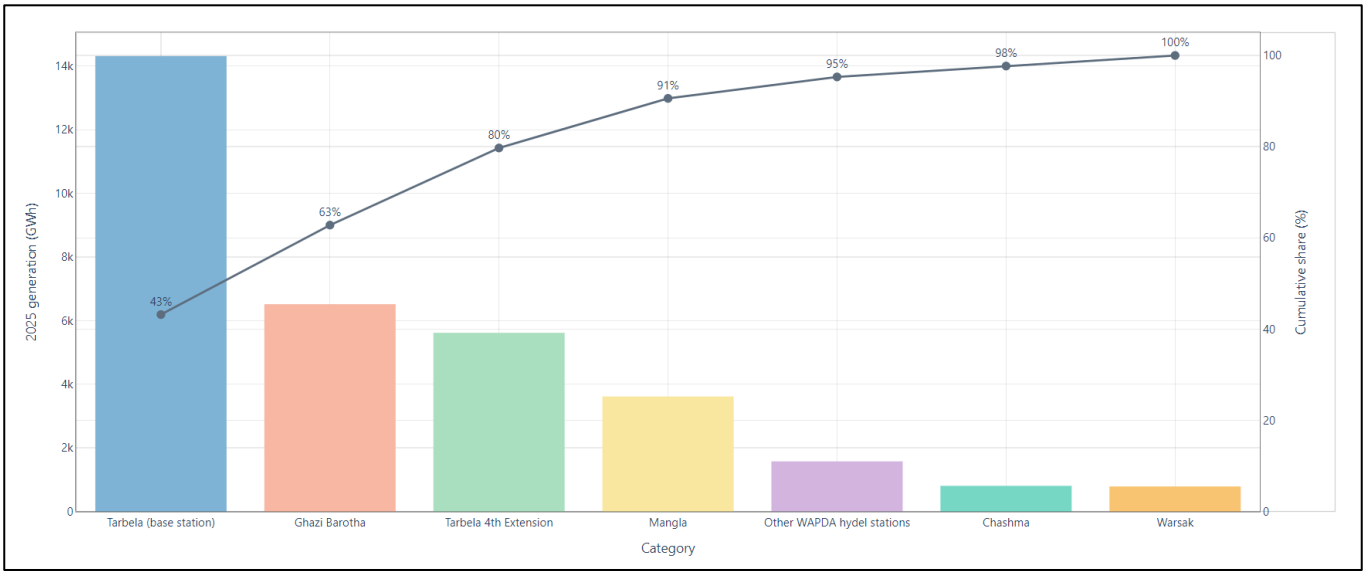


Figure 9.2. WAPDA hydel generation by major station/group, calendar year 2025.
Source: WAPDA (30 December 2025). Values are reported actual annual generation, unlike the design/average annual-energy values used for future projects.

9.3 Development pipeline: capacity, energy and storage functions differ sharply among projects

The hydro pipeline contains fundamentally different project types. Diamer Basha is a large multipurpose storage project with 4,500 MW of planned capacity, 18,097 GWh/year of annual energy, 8.10 MAF gross storage and 6.40 MAF live storage. Mohmand combines 800 MW of generation with about 1.29 MAF gross storage and major irrigation, flood-control and municipal-water functions. Dasu Stage I is a high-energy run-of-river scheme of 2,160 MW and about 12,225 GWh/year. Tarbela Fifth Extension, by contrast, reuses existing reservoir/tunnel infrastructure and the latest WAPDA update gives 1,530 MW but only about 1.466 billion kWh/year, illustrating why installed MW alone is a poor measure of annual system contribution.

Projects listed by WAPDA as ready for construction further expand the range: Lower Palas Valley (665 MW; 2,590 GWh/year), Lower Spat Gah (496 MW; 2,007 GWh/year) and Bunji (7,100 MW; 24,760 GWh/year). The synthesis stores these as design values. Their future economic ranking requires current construction cost, financing, environmental and resettlement costs, transmission scope and hydrological risk.

9.4 Seasonality, storage and the water-energy nexus

Hydropower cannot be optimized independently of Pakistan's water system. The same Indus Basin stores and releases water for irrigation, flood management, municipal supply and electricity. The Economic Survey reports average river receipts of 138.4 MAF/year but also emphasizes seasonal and climatic variability and limited live storage. WAPDA notes that Ghazi Barotha can provide peak production in May and June when generation from Tarbela and Mangla is reduced, an example of how different hydro assets can complement one another within the same river system.



Figure 9.3. Selected Pakistan hydropower projects: installed capacity versus published annual energy.

Source: WAPDA, PPIB and World Bank project evidence compiled in the companion evidence database. Status symbols distinguish operating, under-construction and ready-for-construction projects; annual energy is not necessarily actual generation.

The evidence base still lacks a harmonized, bankable pumped-storage site dataset containing head, active storage, geotechnical conditions, interconnection requirements, environmental constraints, round-trip efficiency, CAPEX and dispatch value. Pumped storage therefore remains a screened option rather than a quantified national build target.

9.5 Pumped storage: potentially valuable, but the evidence base is still pre-project

NEPRA's State of Industry Report 2023 records that PPIB was carrying out an assessment to identify pumped-storage hydropower sites to address the intermittency of wind and solar and supplement peak demand. That official evidence supports pumped storage as a recognized planning option, but this chapter does not identify a public, confirmed bankable utility-scale Pakistan pumped-storage project with the head, active storage, geotechnical, environmental, grid and cost data needed for full economics.

Accordingly, the companion evidence database treats pumped storage as a screening workstream. Candidate sites will need at minimum: upper/lower reservoir geometry, usable head, active volume, conveyance length, geotechnical conditions, evaporation/water balance, round-trip efficiency, charging-energy profile, transmission distance, environmental and resettlement constraints, and CAPEX/OPEX. A generic round-trip-efficiency assumption is deliberately not inserted into the evidence database before a source-controlled design case is selected.

9.6 Project economics: existing hydro can be cheap, while new hydro remains capital-intensive

The public evidence already shows why “hydro cost” cannot be represented by one number. The 102 MW Gulpur run-of-river project was estimated at about US$365 million including contingencies, with 25% equity, 75% debt, a 30-year PPA and expected generation of 465 GWh/year. A World Bank financing document for Dasu Stage I described the 2,160 MW scheme as a US$4.6 billion investment and separately estimated a 765 kV transmission line at about US$715.3 million. Tarbela Fifth Extension benefits from existing dam infrastructure and is supported by US$390 million from the World Bank and US$300 million from AIIB, but those financing commitments are not the same as total project cost.

Chapter 19 therefore normalizes project cost, energy output, tariff vintage, financing structure and evidence class before drawing cross-technology conclusions.

9.7 Hydropower synthesis and development implications

Hydropower is already a large, indigenous and operationally important component of Pakistan's power system, and the identified resource base remains substantial. Its future value, however, is conditional on hydrology, storage function,

water allocation, construction/financing risk and transmission. Pumped storage could become a high-value complement to variable renewables, but it remains an evidence-acquisition and site-screening problem in this synthesis rather than a quantified national capacity claim.

10. Solar Energy

10.1 Decision question: abundant resource, but delivered value depends on location, timing and grid access

Solar PV is now a major part of Pakistan's changing capacity base, especially because distributed and net-metered systems can be added faster than conventional generation. The analytical challenge is to distinguish physical solar resource, measured irradiation, modelled PV yield, installed capacity, behind-the-meter production, grid-supplied generation, curtailment and delivered system value. A high GHI location is not automatically the least-cost project once land, interconnection, transmission, cleaning water, temperature and financing are included.

10.2 Public measurement and GIS evidence is unusually strong

A major advantage for this synthesis is the existence of open measurement data. World Bank/ESMAP's Pakistan Solar Radiation Measurement Data repository contains measurements from nine automated stations: Bahawalpur, Hyderabad, Islamabad, Karachi, Khuzdar, Lahore, Multan, Peshawar and Quetta. The catalog describes 10-minute averages for solar radiation, temperature, air pressure and wind speed, with QC and raw files available under a CC BY 4.0 license. The initial catalog temporal coverage is 2015-2017, and the catalog notes continued operation from 2018 by the Government of Pakistan with NREL and USAID.

The companion evidence database registers the public solar-resource measurement network, atlas layers and selected Balochistan resource indicators so that measured evidence remains distinguishable from mapped or modelled potential.

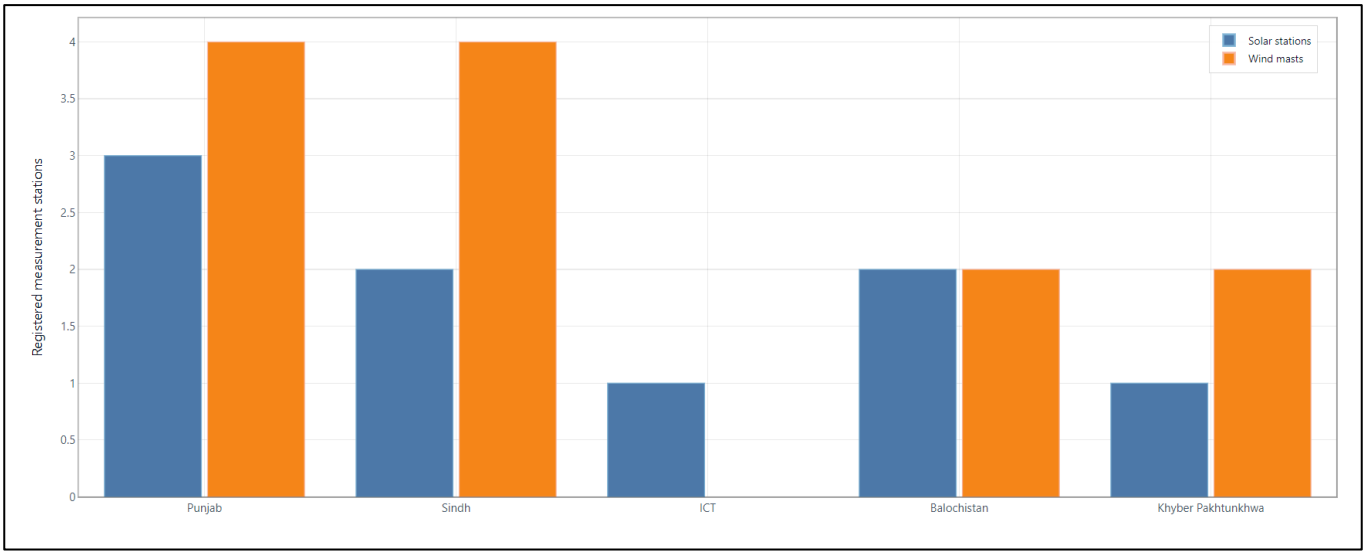


Figure 10.1. Public World Bank/ESMAP solar-station and wind-mast measurement-network coverage used in this synthesis.

Source: World Bank/ESMAP ENERGYDATA.info solar and wind measurement repositories. The figure shows measurement-site coverage only; it is not a resource-quality ranking.

10.3 Capacity growth confirms rapid deployment, but accounting requires care

IRENA's standardized series records Pakistan solar capacity rising from 589 MW in 2016 to 3,717 MW in 2024 and remaining at that value in the 2025 capacity table used in this synthesis. National 2026 capacity statistics report a much larger renewable total because the Pakistan Economic Survey includes 7,319 MW of net-metering capacity in its

renewable category. These are different statistical systems and should not be merged without reconciling distributed/off-grid definitions and year-end versus fiscal-period timing.

10.4 Balochistan illustrates the difference between resource quality and delivery infrastructure

The World Bank's Balochistan Renewable Energy Development Study identifies the province as having particularly strong and low-cost renewable-resource opportunities. The report cites solar-resource/PV-potential values of roughly 2,000-2,500 kWh/m2/year, DNI up to about 2,500 kWh/m2/year in some areas and modelled PV grid-utilization factors up to 35%. These are regional study/model indicators, not measured output from an operating project.

The 2021 VRE Locational Study makes the transmission trade-off explicit. It found that the earlier 20% VRE target could largely be pursued using spare capacity at existing substations, while the 30% target would require larger investments including hybrid parks and dedicated transmission. Western Balochistan was identified as a high-resource long-term opportunity, including a conceptual Chagai-Muzaffargarh HVDC corridor of roughly 1,000 km. This means the correct solar metric is not plant LCOE alone but delivered cost at a demand node after interconnection and grid reinforcement.

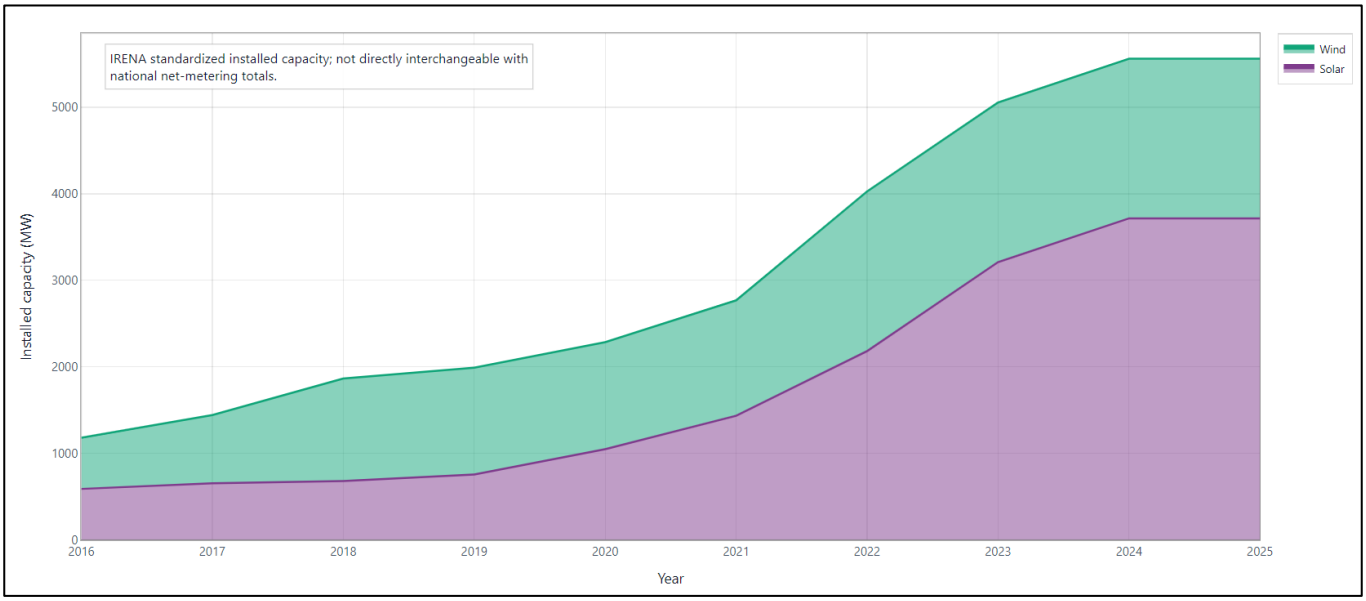


Figure 10.2. Pakistan solar and wind installed capacity in the IRENA standardized series, 2016-2025.

Source: IRENA (2026), Renewable Capacity Statistics 2026. These standardized capacity values should not be equated directly with national net-metering totals without definition reconciliation.

10.5 Solar economics: project vintage matters

The project evidence assembled in Chapters 18-19 demonstrates that published CAPEX, levelized tariff and current payable tariff are different economic quantities and must not be ranked as though they were directly interchangeable.

At utility scale, Balochistan study cases also show why evacuation must be included. The study's conceptual Chagai hybrid park is explicitly modelled together with an HVDC line and reports lower expected PPA values only at large scale. Those values are scenario outputs, not awarded tariffs, but they are useful for testing whether high-quality remote resource can justify dedicated transmission.

10.6 Water, land and distributed-system considerations

Solar PV generally has low operational water demand relative to wet-cooled thermal generation, but Pakistan-specific design must still account for module cleaning in dusty regions, water quality, labor/robotic cleaning alternatives and local water scarcity. Land-use impacts also differ between distributed rooftops, canal/industrial sites and greenfield utility parks. The final regional portfolio should therefore distinguish distributed solar, substation-proximate utility solar and remote high-resource solar rather than applying one national solar cost.

10.7 Solar synthesis and development implications

Chapter 19 uses historical project evidence to reconstruct cost architecture while preserving project vintage, financing structure and tariff status.

11. Wind Energy

11.1 Decision question: strong corridors exist, but curtailment makes grid value explicit

Wind is analytically important because Pakistan already has an operating wind fleet, public mast measurements and identified high-quality corridors, yet current evidence also demonstrates that resource quality alone does not guarantee usable generation. Wind development must therefore be evaluated together with substation capacity, transmission, forecasting, reactive-power support, curtailment and the temporal complementarity of wind with solar and demand.

11.2 Open measurement and atlas datasets provide a reproducible resource foundation

World Bank/ESMAP's Pakistan Wind Measurement Data repository contains data from 12 wind masts at Bahawalpur, Chakri, Gwadar, Haripur, Peshawar, Quaidabad, Quetta, Sadiqabad, Sanghar, Sujawal, Tando Ghulam Ali and Umerkot. The catalog records 2016-2018 temporal coverage and provides wind speed, wind direction, air pressure, relative humidity and temperature together with QC/raw files and site reports. A complementary World Bank/Global Wind Atlas dataset provides wind-speed, wind-rose and wind-power-density GIS layers under CC BY 4.0.

The companion evidence database registers the public wind-mast measurement network, atlas layers and selected resource indicators so that field measurements and modelled resource layers remain traceable.

11.3 Installed capacity has grown, but growth slowed in the standardized series

This synthesis therefore treats operating wind capacity and mapped wind-resource potential as separate evidence streams.

11.4 Sindh and Balochistan offer different development propositions

The VRE Locational Study confirms continued opportunity in the southern Sindh wind corridors around Jhimpir and Gharo while identifying western Balochistan as a much larger long-term solar-wind opportunity requiring substantial transmission. The 2024 Balochistan study reports best-area wind speeds up to about 10 m/s at 100 m in remote Chagai and Panjgur and describes about 15 GW of generation potential in those high-quality zones. That is a study potential estimate, not a current project pipeline or bankable reserve.

The Balochistan study also develops a hybrid-park concept in Chagai. It examines an initial 2 GW development and a larger cost-optimal combination of roughly 3 GW wind plus 4 GWp solar connected through a 4 GW HVDC line, with a full-scale modelled PPA range of approximately 6.46-6.66 US cents/kWh including evacuation. These figures are useful scenario evidence because they internalize transmission; they are not observed tariffs and should not be used as a current bid benchmark.

11.5 The 2026 grid-stability project converts curtailment from an abstract risk into a measured planning problem

In July 2026 the World Bank approved US$375.9 million for the Grid Stability Enhancement Project under BEST-PAK. The study is designed to add STATCOMs at three major 500 kV substations and reactive-power equipment across 26 substations. The World Bank states that these upgrades are intended to bring 640 MW of currently curtailed wind energy onto the grid, enable full use of 1,840 MW of wind capacity in southern Pakistan and support integration of about 491 MW of planned private renewable projects.

This is a major resource-integration finding: high-quality wind resource is valuable only where transmission, dispatch, flexibility and project economics permit it to be converted into useful delivered energy.

11.6 Solar-wind complementarity and hybrid parks

Chapters 19 and 21 test complementarity rather than assuming that low stand-alone generation cost is sufficient for system value.

11.7 Wind economics and project-vintage normalization

The Hydro China Dawood wind project in the companion evidence database provides a historical Pakistan project-finance case: 49.5 MW gross capacity, about US$122.94 million reported project cost, a 32.7% net capacity factor and a historical levelized tariff of 13.5244 US cents/kWh. IRENA's 2024 global weighted average for newly commissioned onshore wind was about US$1,041/kW with LCOE of US$0.034/kWh. The large difference is not evidence of a simple overpricing conclusion because the projects differ by vintage, financing, local supply chain, grid scope and tariff structure. Chapter 19 normalizes these factors before cross-technology comparison.

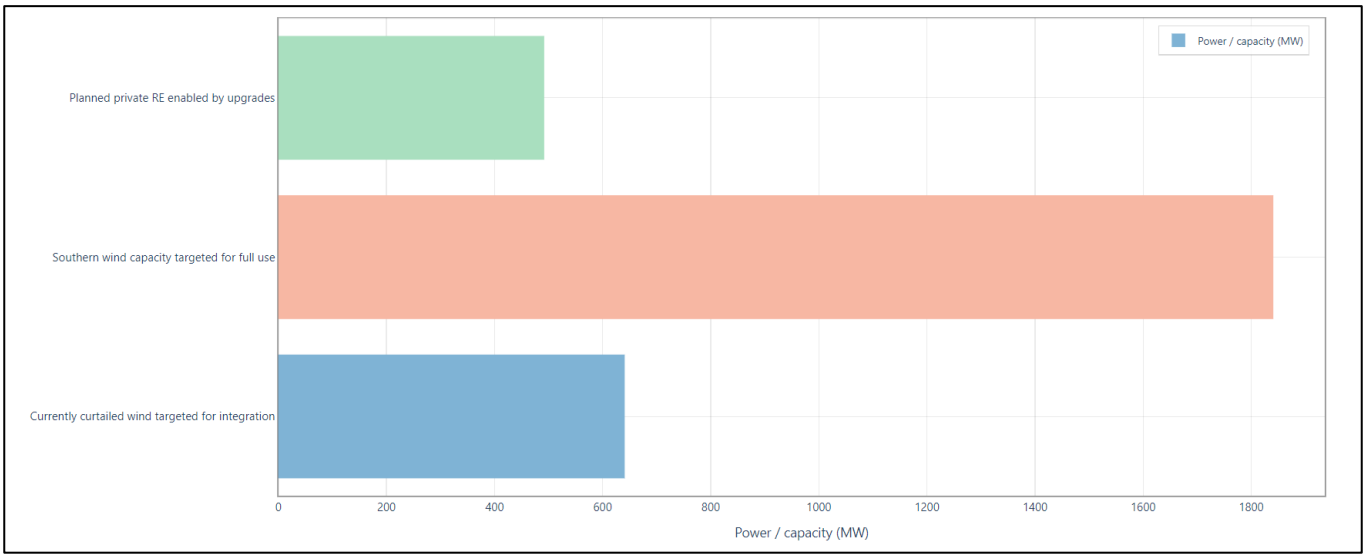


Figure 11.1. Renewable-integration quantities cited for the 2026 BEST-PAK Grid Stability Enhancement Project.

Source: World Bank (2026). The 491 MW figure is planned private-sector renewable integration; the 640 MW figure is the study's stated currently curtailed wind targeted for recovery.

11.8 Wind synthesis and development implications

Pakistan has measured wind resources, operating wind capacity and significant remaining high-resource areas, but the 2026 grid evidence makes transmission and stability a first-order economic variable. Near-term wind additions should therefore prioritize sites with strong measured resource and demonstrable grid hosting/evacuation capacity, while very large western Balochistan opportunities should be evaluated as integrated generation-plus-transmission systems.

11.9 Integrated renewable-resource synthesis

The resource-specific synthesis materially strengthens the case for evaluating wind together with solar, storage, transmission and demand rather than as an isolated technology.

12. Coal, Oil and Gas

12.1 Decision question: indigenous security value versus delivered system cost

Coal, oil and gas remain central to Pakistan's energy-security problem because they combine domestic resource potential, import exposure, foreign-exchange risk and firm-energy value. The resource question is therefore not whether hydrocarbons should be treated as uniformly desirable or undesirable. It is which uses are economically and strategically defensible after fuel origin, utilization, plant efficiency, water, emissions, financing and system alternatives are

considered together. This chapter establishes that resource-specific frame; the realized FY2024-25 operating-economics closure is revisited in Chapter 34.

12.2 Petroleum and LNG/RLNG imports: foreign-exchange exposure is broader than oil products alone

For energy-security analysis, the broader petroleum-group import account is more informative than a petroleum-products-only chart. During July-March FY2026, the Pakistan Economic Survey reports total petroleum-group imports of about US$11.25 billion, equal to 22.2% of total goods imports. Crude oil accounted for roughly US$4.5 billion and petroleum products about US$4.1 billion. LNG imports fell 29.7% year on year but still represented approximately US$1.9 billion of foreign-exchange exposure. This is economically important because the imported LNG is subsequently regasified as RLNG and used in power, industry and other gas-consuming sectors. The same Survey also notes that Middle East tensions reversed earlier price moderation, with Brent crude rising from about US$62.7/bbl in December 2025 to US$103.7/bbl in March 2026. The implication is that import dependence must be stress-tested against fuel-price, freight and exchange-rate shocks rather than represented by physical volume alone (Government of Pakistan, 2026, Trade and Payments).

The FY2024-25 Yearbook provides the preceding complete annual anchor: about US$11.4 billion for the reported oil import bill, plus 8.74091 MTOE of LNG imports valued at about US$3.371 billion. The annual and Jul-Mar FY2026 values are therefore used as a sequence, not concatenated into one figure. This improves the distinction between physical import volume, foreign-exchange exposure and the later domestic use of regasified LNG as RLNG (HDIP, 2026).

Table 12.1. Pakistan petroleum-group import exposure, Jul-Mar FY2026.

Import component	Approx. value (US$ bn)	Evidence basis	Energy-security interpretation
Petroleum crude	~4.5	Official FY2026 Trade & Payments narrative	Large direct FX exposure; refinery/transport dependence.
Petroleum products	~4.1	Official FY2026 Trade & Payments narrative	Transport and product demand; not wholly substitutable by power-sector change.
Imported LNG (regasified as RLNG)	~1.9	Approximate: FY2025 PBS value adjusted by the reported 29.7% FY2026 decline	Major imported-gas/FX exposure; relevant to RLNG-fired power and gas allocation.
LPG and other petroleum-group items	~0.75	Approximate residual to the reported petroleum-group total	Smaller but still imported fuel exposure.
Total petroleum group	11.246	Pakistan Economic Survey 2025-26, Fig. 8.10	22.2% of total goods imports during Jul-Mar FY2026.

Source: Government of Pakistan (2026), Pakistan Economic Survey 2025-26, Trade and Payments; Pakistan Bureau of Statistics. Rounded/derived values are explicitly identified. LNG import payments refer to LNG at import; domestic consumption is reported as RLNG after regasification.

The national energy-import cost comparison is shown in Figure 7.1 (Chapter 7) and is not repeated here.

12.3 Natural gas and RLNG: fuel origin changes the security interpretation

The same distinction is essential for natural gas. During July-March FY2026, total reported gas consumption was about 2,929 MMCFD, including about 2,316 MMCFD of indigenous gas and 613 MMCFD of RLNG. The power sector consumed 924 MMCFD, of which 405 MMCFD was RLNG, while general industry consumed 382 MMCFD, including 122 MMCFD of RLNG. Domestic and fertilizer demand remained much more heavily dependent on indigenous gas. Figure 7.1 adds the financial dimension: even after a 29.7% year-on-year decline, LNG imports still cost roughly US$1.9 billion during the first nine months of FY2026. An avoided-MWh calculation must therefore identify whether it displaces imported RLNG,

scarce indigenous gas, or another fuel altogether; otherwise the foreign-exchange and opportunity-cost benefit can be misstated (Government of Pakistan, 2026, Table 14.9; Trade and Payments).

The Yearbook also separates resource inventory from deliverability. FY2024-25 natural-gas production declined to about 2,890 MMCFD even as proved gas reserves increased to 23.31 Tcf. For economics, a reserve addition is therefore not treated as a substitute for current flow capacity, pipeline deliverability, seasonal allocation or imported-LNG exposure (HDIP, 2026). The sectoral indigenous-gas and RLNG comparison is shown in Figure 7.2 (Chapter 7) and is not repeated here.

The Pakistan Energy Outlook 2021-2030 had projected increasing LNG dependence as indigenous gas declined. In this synthesis that forecast is retained as a historical planning benchmark, not as a current observation. Its value is in testing whether the earlier diagnosis of import exposure remains directionally relevant when compared with newer FY2026 data (Ministry of Planning, Development & Special Initiatives, 2022).

12.4 Residual furnace oil: still operational, but current economics are dominated by fuel cost

Residual furnace oil (RFO) remains part of Pakistan's operating power fleet and therefore requires an explicit economics case rather than being hidden inside a generic petroleum category. As of 30 June 2026, PPIB lists six operational RFO IPPs - Kohinoor, Attock Gen, Nishat Power, Nishat Chunian, Liberty Power Tech and HUBCO-Narowal - with a combined gross capacity of about 1,116 MW. Nishat Power provides a representative plant-level case: 200 MW gross / 195 MW dependable capacity, reciprocating-engine technology, a 25-year PPA and commercial operation since 2010 (PPIB, 2026; PPIB, n.d.).

Current fuel evidence also shows why RFO cannot be represented by historical plant CAPEX alone. For January 2026, NEPRA approved a revised Nishat Power RFO price of PKR 187,191.14 per metric tonne and a fuel-cost component of PKR 36.8213/kWh. A separate 2025 fuel-price decision records petroleum levy of PKR 82,077/MT and climate-support levy of PKR 2,665/MT in the RFO price basis. These are fuel-cost inputs, not an all-in project tariff, LCOE or forward system cost. The economics workflow therefore treats RFO as an existing-asset fuel/dispatch case with explicit fuel price, levy, FX, utilization and uncertainty fields; a full DCF remains gated by current O&M, all tariff components, remaining-life financing and dispatch evidence (NEPRA, 2025; NEPRA, 2026).

12.5 Coal: a large indigenous resource, but system economics depend strongly on utilization

Pakistan's Thar lignite resource is strategically important because it can substitute for imported fuel in selected uses, but resource abundance alone does not establish the optimal scale of future coal development. The FY2024-25 NEPRA operating dataset provides a much stronger economic test than national fuel-share arguments alone. The local Thar-coal portfolio in the dataset operated at 72.9% utilization and generated about 15.55 TWh, while the imported-coal portfolio operated at only 22.9% utilization and generated about 8.70 TWh.

At national scale, HDIP reports 18.75 million tonnes of domestic coal production, 6.98 million tonnes of imports, 25.73 million tonnes of consumption and a PKR 203 billion import bill in FY2024-25, against 7,775.5 million tonnes of measured coal reserves. The resulting security question is therefore not simply resource abundance, but how much domestic supply can be delivered at competitive full system cost under water, mine, transport, plant and financing constraints (HDIP, 2026).

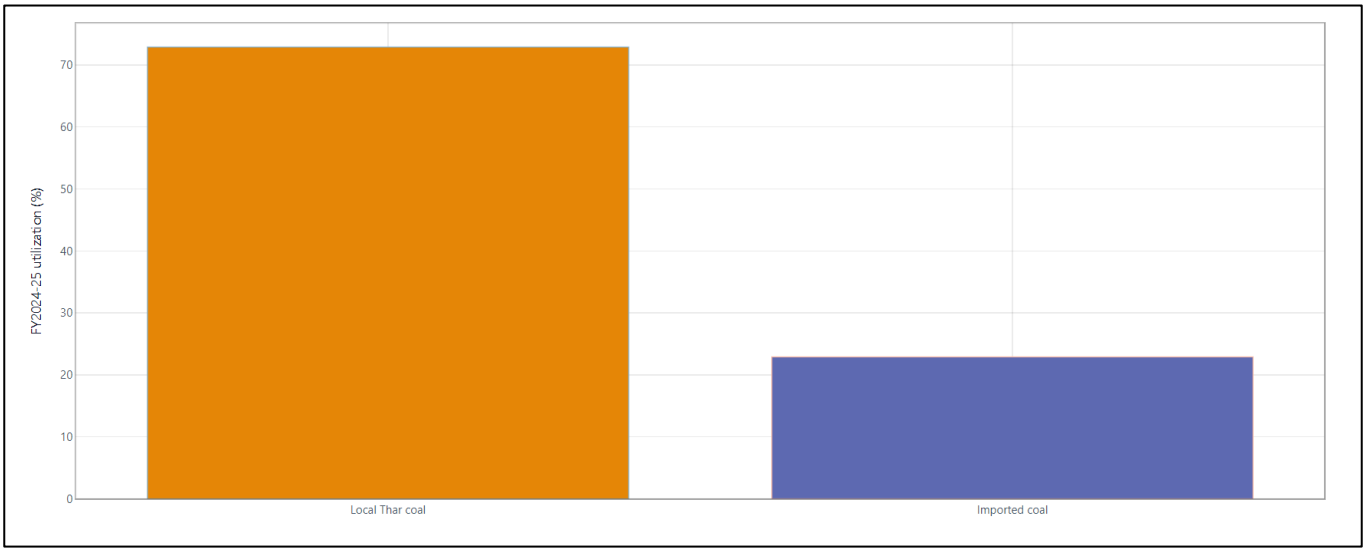


Figure 12.1. Local Thar versus imported-coal utilization, FY2024-25.

Source: NEPRA (2026), Performance Evaluation Report of Operational Power Plants FY2024-25; companion evidence database synthesis.

12.6 Capacity-payment dilution is part of the fuel-choice problem

The same-year annual procurement-cost proxy is approximately 30.10 PKR/kWh for local Thar coal and 65.61 PKR/kWh for imported coal. The decomposition is more important than the headline difference: the capacity-component proxy is about 16.47 PKR/kWh for local coal versus about 47.58 PKR/kWh for imported coal. The result does not prove that local coal is always cheaper. It shows that, in FY2024-25, low utilization greatly amplified the per-kWh burden of contracted imported-coal capacity, so fuel price cannot be interpreted independently of dispatch and fixed-cost recovery.

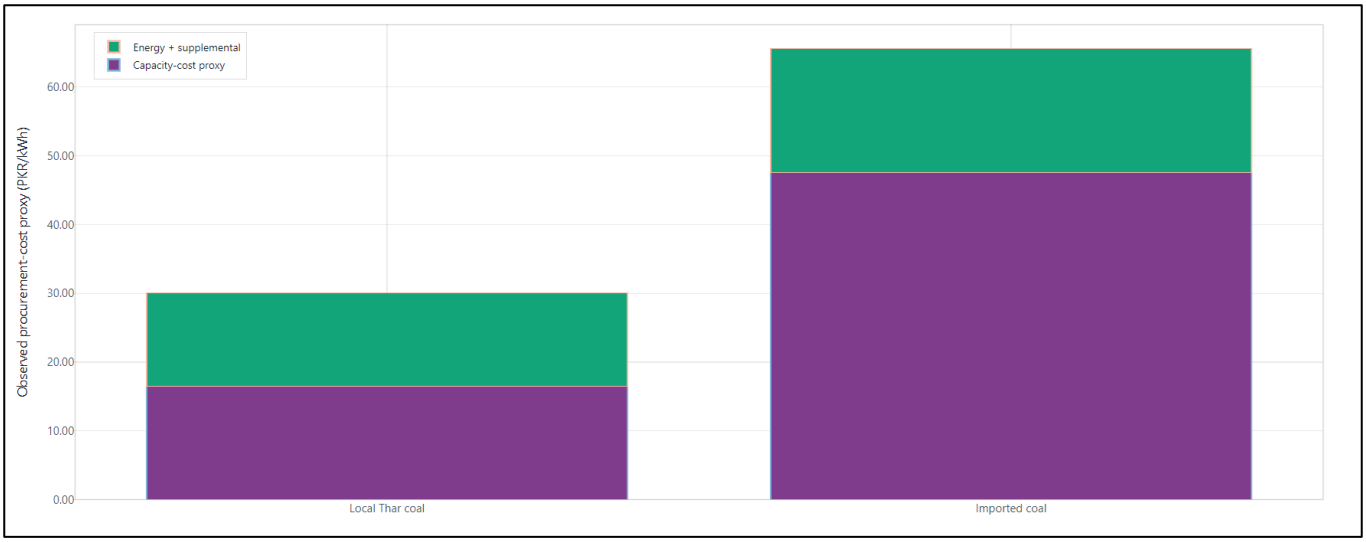


Figure 12.2. Local Thar versus imported-coal observed annual procurement-cost decomposition, FY2024-25.

Source: NEPRA (2026), FY2024-25 plant-performance evidence; procurement-cost proxies are derived from reported annual payments and net generation and are not plant LCOE.

12.7 Water, emissions, financing and infrastructure remain binding constraints

The observed annual-cost advantage of the local-coal portfolio should not be generalized into a technology endorsement. New mine and plant economics still require mine-mouth cost, transport and handling, plant efficiency, cooling-water requirement, local air pollutants, carbon exposure, ash management, grid reinforcement, financing terms and remaining asset life. RLNG economics remain exposed to international fuel prices, foreign exchange and dispatch; indigenous gas has an alternative value in fertilizer, industry and domestic demand. Petroleum substitution also depends

on transport and refinery structure. These constraints are retained explicitly rather than folded into one headline cost number.

12.8 Integrated coal, oil and gas synthesis

The evidence supports a conditional portfolio conclusion. Indigenous fuel can have energy-security value where it reduces avoidable import exposure, but the economic benefit must be demonstrated at delivered-system level. Imported-fuel assets may still provide valuable flexibility or capacity, while domestic resources can become expensive if water, environmental, financing or network burdens are ignored. For Brill-Viz Economics, the appropriate workflow is therefore fuel-origin specific: separate indigenous gas from RLNG, separate local from imported coal, retain RFO/liquid-fuel economics as a distinct fuel-cost and dispatch case, and stress-test FX and commodity prices probabilistically, and preserve observed utilization as a major driver of realized annual cost.

> *Evidence boundary: the procurement-cost figures above are observed annual system-payment intensities, not project LCOE, NPV or forward tariff forecasts. Chapter 34 retains the detailed realized-performance closure and current tariff/fuel cautions.*

13. Nuclear Energy

13.1 Decision question: firm low-carbon output, but project economics are unit- and vintage-specific

Nuclear power provides firm electricity with low direct fuel-volume exposure, but its economic role cannot be represented by one global LCOE or one fleet-average number. Pakistan's current evidence shows that utilization, capital recovery, financing structure, unit vintage, outage pattern, water interface and project-specific debt terms materially affect delivered cost. The resource question is therefore not simply whether nuclear is 'cheap' or 'expensive', but where its firm-energy and reliability value justifies the associated capital, financing, water and construction risks.

13.2 FY2024-25 fleet performance establishes a strong operating benchmark

Pakistan's nuclear fleet generated about 22.45 TWh in FY2024-25 at an aggregate utilization factor of 78.5%. The companion evidence database derives an average CPP+EPP procurement-cost proxy of about 18.49 PKR/kWh. That portfolio average, however, conceals substantial unit-level variation and should not be applied indiscriminately to a future plant or to C-5.

13.3 Unit-level utilization and payment intensity vary materially

The six operating units in the FY2024-25 dataset show a wide spread. K-2 combines about 83.6% utilization with an observed annual procurement-cost proxy near 10.39 PKR/kWh, while K-3 combines about 63.5% utilization with a proxy near 31.79 PKR/kWh. The Chashma units occupy intermediate positions. This dispersion reinforces a central synthesis finding: high fixed-cost technologies must be assessed with actual utilization and financing/capital-recovery structure, not by technology label alone.

13.4 C-5 provides an approved investment case, not yet a completed bankability case

The approved C-5 PC-I reports a total rationalized project cost of PKR 1,047,988.84 million, gross/net capacity of 1,100/1,017.5 MW and an 81-month implementation period. On those capacity definitions, the approved cost is approximately PKR 0.953 million/kW gross and PKR 1.030 million/kW net. The same PC-I reports PKR 820,742.99 million as Chinese supplier credit/foreign aid and PKR 187,098.96 million as FEC; those two reported fields are retained separately and are not assumed to be equivalent accounting categories. These data provide a strong capital-cost anchor but do not by themselves determine tariff, IRR, DSCR or consumer affordability.

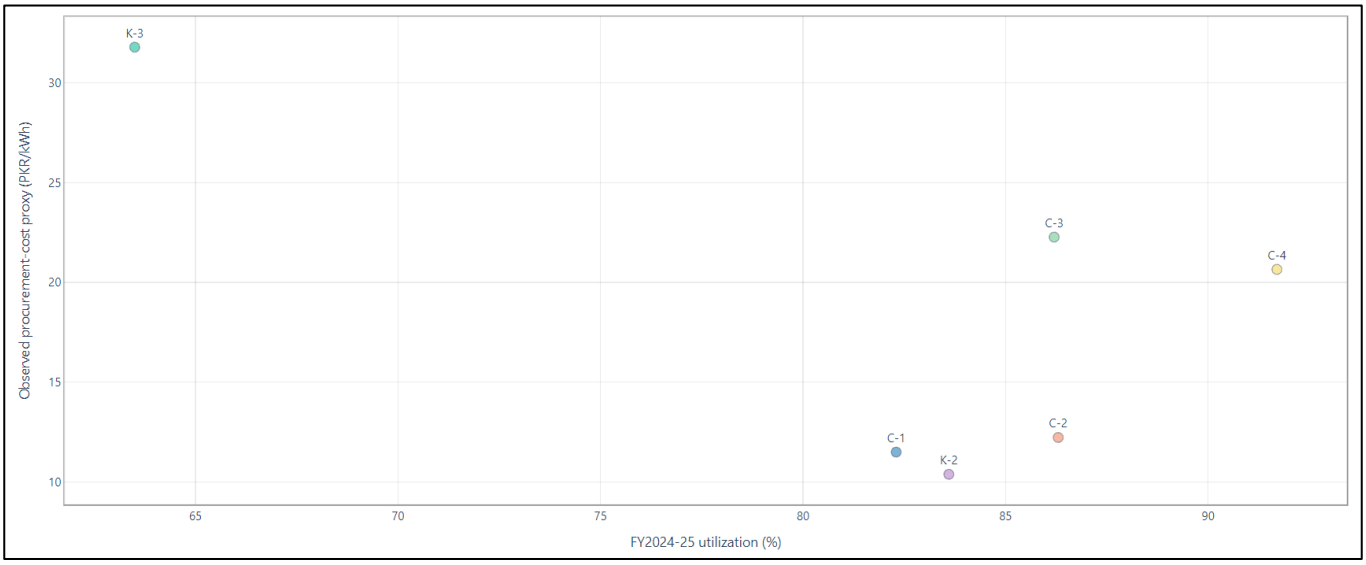


Figure 13.1. Pakistan nuclear units: FY2024-25 utilization versus observed annual procurement-cost proxy.

Source: NEPRA (2026), FY2024-25 plant-performance evidence; derived procurement-cost proxy from reported CPP, EPP and net generation.

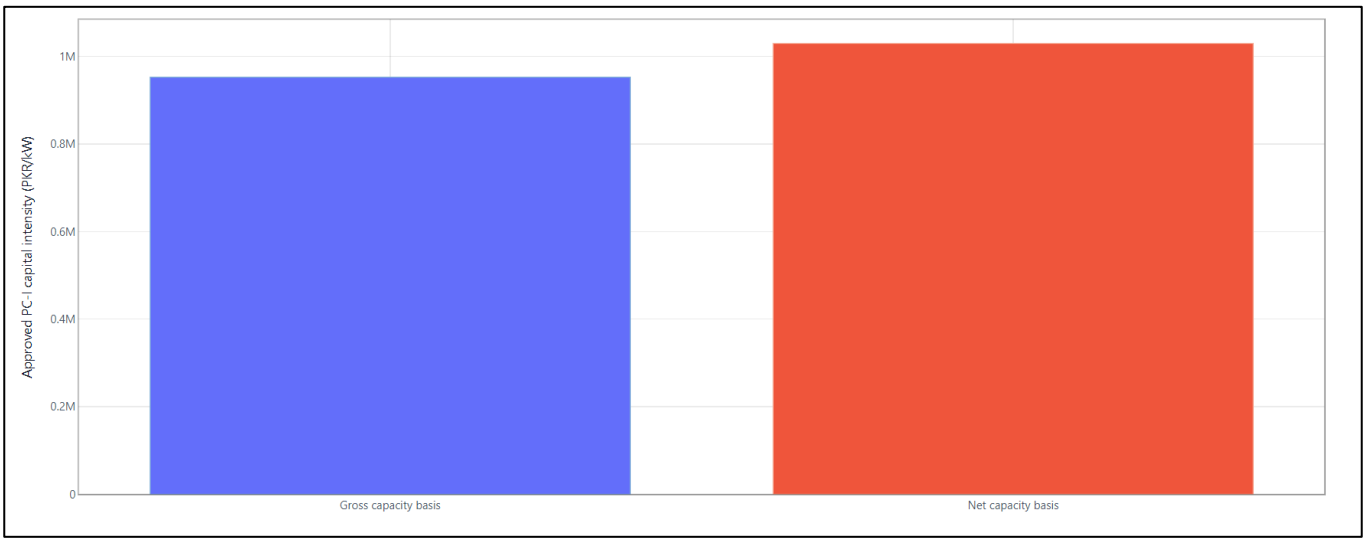


Figure 13.2. C-5 approved PC-I capital intensity on gross and net capacity bases.

Source: Planning Commission C-5 PC-I evidence in the companion database. Capital intensity is derived from the approved cost and reported gross/net capacity; it is not a tariff or project-return metric.

13.5 Water is a large physical interface but withdrawal must not be confused with consumption

WAPDA's FY2022-23 reporting records 1.960 MAF of cooling-water supply to the Chashma nuclear complex, ultimately returned to the river, together with a continuous 3,540-cusec CJ-Link supply to C1-C4. The reported 1.960 MAF corresponds to roughly 2.42 billion cubic metres of annual supply. It is nevertheless a withdrawal/supply measure, not evidence that the same volume is consumptively lost. Site evaluation must distinguish withdrawal, return flow, evaporative consumption and water quality, and the existing C1-C4 operating supply must not be treated as the C-5 design requirement without project-specific evidence.

13.6 Integrated nuclear synthesis and Brill-Viz treatment

The evidence supports nuclear as an important firm-energy component of Pakistan's portfolio, but it also requires project-specific economics. Brill-Viz should therefore model C-5 and any future nuclear case with its actual construction schedule, financing, debt service, fuel/O&M, outage and water assumptions rather than importing a generic global nuclear cost. Probabilistic cases should emphasize construction duration, capital escalation, interest rates, FX exposure

and utilization. The FY2024-25 fleet data provide operating calibration; the PC-I provides capital evidence; the remaining tariff and financing details are the bankability gate.

> *Evidence boundary: the unit-level procurement-cost proxy is an observed annual payment-intensity measure. C-5 approved project cost is not a tariff and not an investment-return calculation. Chapter 35 retains the detailed C-5 financing and water evidence closure.*

14. Bioenergy and Waster

14.1 Decision question: existing agro-industrial cogeneration is real, but national resource potential must remain evidence-led

Bioenergy is often discussed as a generic renewable category, but Pakistan's strongest current evidence is more specific: operating bagasse cogeneration linked to the sugar industry. This provides a real fleet, project-cost history and industrial heat-power integration experience. It does not automatically establish a national biomass or waste-to-energy potential, because recoverable feedstock depends on residue ratios, moisture and calorific value, mill self-use, competing uses, collection radius, seasonality and logistics.

14.2 The FY2024-25 bagasse fleet is heterogeneous rather than one uniform technology case

NEPRA reports 302 MW installed and 254 MW reference capacity across the bagasse plants represented in the FY2024-25 operating dataset, with about 670 GWh of net generation and a portfolio utilization factor of 30.1%. The derived portfolio CPP+EPP procurement-cost proxy is about 32.33 PKR/kWh. The average is not representative of every plant: JDW-II and JDW-III operated near 89.8% and 85.8% utilization, whereas Chanar and Shahtaj were close to 1-2%. Feedstock strategy, cogeneration configuration, industrial steam demand, seasonal operation and off-season fuel arrangements therefore have to be modelled explicitly.

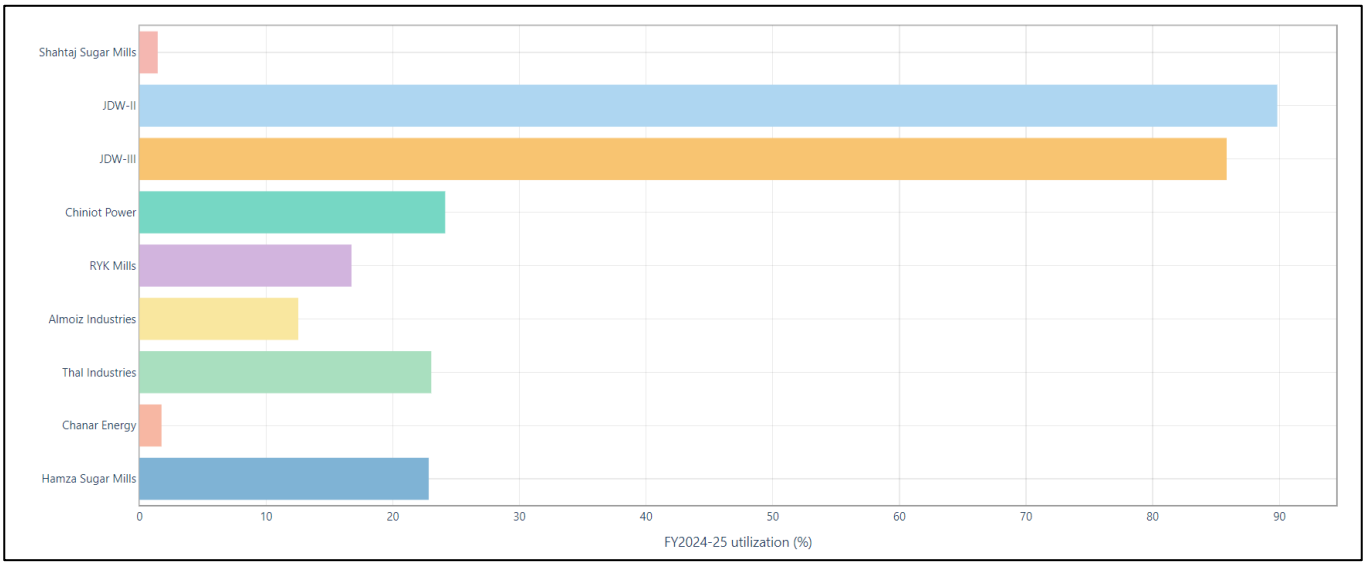


Figure 14.1. Bagasse cogeneration utilization dispersion, FY2024-25.

Source: NEPRA (2026), FY2024-25 plant-performance evidence. The dispersion shows why a single national bagasse capacity factor is not defensible.

14.3 Historical project-cost evidence provides a useful capital-architecture benchmark

PPIB project records provide a consistent historical family for several commissioned bagasse projects. Hamza, RYK, Layyah/Thal, Chanar and Almoiz are reported with approximately 80:20 debt-equity structures and 45% annual-availability assumptions. Their reported project prices range from about US$14.95 million for 15 MW to US$40.86 million

for 41 MW, corresponding to roughly US$0.997 million/MW in this selected historical sample. These values are useful for reconstructing project architecture and for Brill-Viz Economics testing, but they are not current new-build bids.

14.4 Feedstock scale is not the same as recoverable energy potential

Pakistan's reported 2025-26 sugarcane production of 89.45 million tonnes establishes the scale of the agro-industrial base but should not be converted directly into electricity potential. A defensible national bagasse estimate requires sourced residue yield, moisture and energy content, mill process heat and self-consumption, competing commercial uses, seasonal storage and transport losses. The same principle applies even more strongly to municipal waste, agricultural residues and biogas: resource quantity, collection system, conversion technology and delivered-energy economics must be separated.

14.5 Waste-to-energy should be screened as a waste-management and energy system, not only as generation

A future waste-to-energy programme should therefore begin with city- and province-specific waste quantity and composition, collection coverage, moisture/organic fraction, landfill baseline, tipping-fee structure, grid connection and environmental controls. Without those inputs, a national MW claim would be less defensible than the operating bagasse evidence already available. Where waste treatment has a separate avoided disposal cost or methane-reduction value, that benefit should be kept visible rather than hidden inside a simple electricity LCOE.

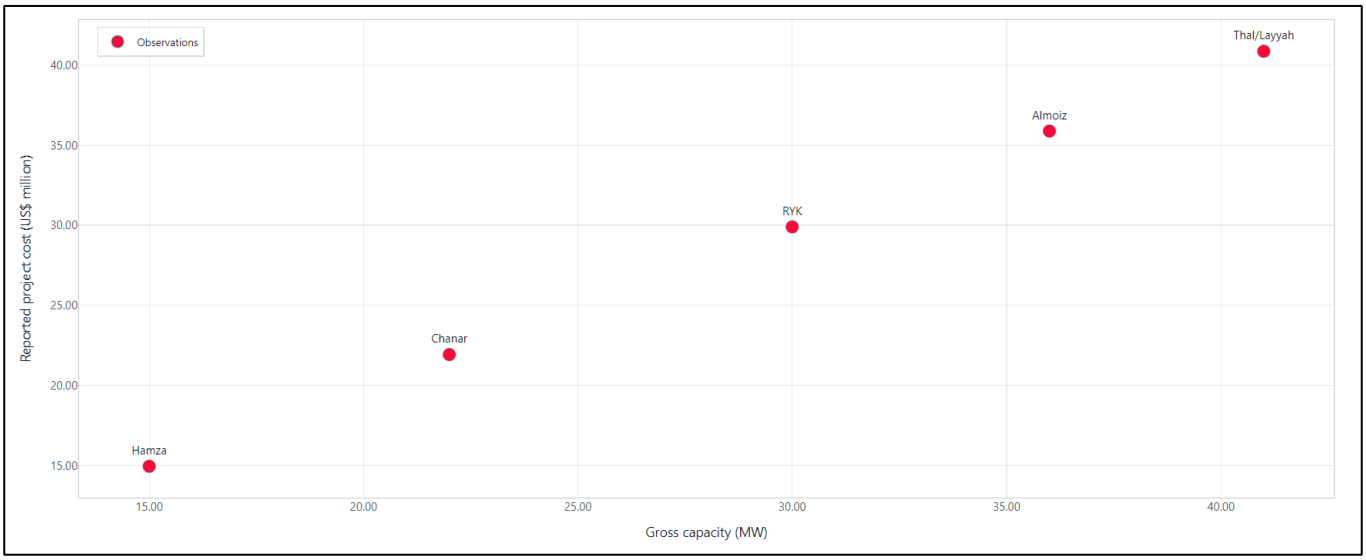


Figure 14.2. Representative Pakistan bagasse projects: historical project cost versus gross capacity.

Source: PPIB project evidence in the companion database. The dashed reference corresponds to approximately US$0.997 million/MW in the selected historical cases; project vintage must be preserved.

14.6 Integrated bioenergy and waste synthesis

The evidence supports bagasse as a genuine operating component of Pakistan's energy portfolio and as a useful distributed industrial cogeneration model, but not as a uniform high-capacity-factor resource. Brill-Viz should model individual projects using plant-specific feedstock, steam/electricity balance, operating season, debt structure, tariff and O&M assumptions. Other biomass, biogas and municipal-waste opportunities should remain screening cases until the feedstock and collection evidence is comparable. This preserves the study's rule that resource potential is not converted into bankable capacity without the engineering and economic chain in between.

> *Evidence boundary: the selected historical bagasse CAPEX cases establish cost architecture, not current replacement cost. Chapter 36 retains the detailed FY2024-25 operating-performance and project-economics closure.*

PART V - SYSTEM INTEGRATION

15. Grid, Transmission and Chronological Operations

15.1 Why chronology changes the answer

Installed capacity is not a chronological reliability metric. NEPRA reports that during FY2023-24 the CPPA-G system had 42,512 MW of installed capacity, while maximum demand reached 30,150 MW, maximum load actually served was 25,516 MW, average annual load served was 18,463 MW and minimum demand fell to 7,015 MW. The peak-to-average relationship therefore creates a fundamentally different planning problem from one based on nameplate capacity alone. A system built only to satisfy a short annual peak can carry substantial fixed cost during lower-load hours; conversely, a system sized to annual averages can fail during peak or contingency conditions (NEPRA, 2024).

Table 15.1. FY2023-24 installed capacity, demand and load-served metrics and their system-integration significance.

Metric	FY2023-24 value	System-integration significance
Installed generation capacity	42,512 MW	Nameplate supply base; not equivalent to available or economic dispatch.
Maximum demand	30,150 MW	Peak planning requirement reported by NEPRA.
Maximum load served	25,516 MW	Below reported maximum demand; points to delivery/supply constraints.
Average annual load served	18,463 MW	Shows typical utilization is far below annual peak.
Minimum demand	7,015 MW	Demonstrates a very wide chronological operating range.

Source: Published system-planning evidence. The values are cited planning/model results, not estimates generated by this study.

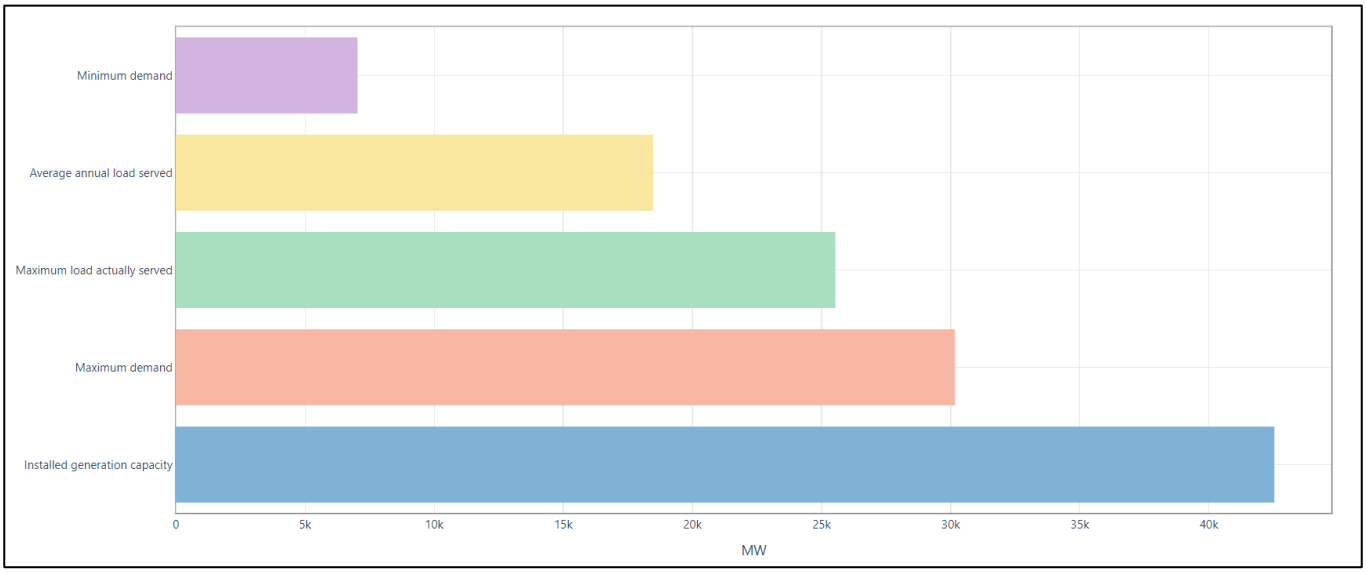


Figure 15.1. Pakistan power-system capacity and load envelope, FY2023-24.

Source: NEPRA (2024), State of Industry Report 2024. Chart reproduces published system metrics.

15.2 A changing daily net-load problem

NEPRA's November 2025 fuel-adjustment record provides a useful current chronological clue. Monthly maximum demand was 14,870 MW at 18:30 on 1 November, while minimum demand was 8,006 MW at 13:00 on 9 November. By

comparison, the November 2024 minimum occurred at 04:00. A representative generation-pattern figure for 5 November 2025 also shows a labelled daytime low of about 8,755 MW followed by an evening high of about 14,368 MW. This is consistent with an increasingly important midday-to-evening ramping problem.

This synthesis does not attribute all observed demand-shape changes to a single cause; distributed solar, weather, economic activity, tariffs and load management can all contribute.

15.3 The economic value of efficient dispatch

The World Bank/ESMAP Planning for Efficient Dispatch study provides a quantified historical test of operational reform. For 2018/19, actual variable generation cost was estimated at USD 5,794 million, whereas the modelled efficient-dispatch case was USD 4,762 million, a modelled saving of USD 1,032 million or 17.8%. The study also shifted utilization toward more efficient CCGT and coal units and away from expensive steam generation. These results are historical and should not be transplanted directly into 2026 economics, but they demonstrate that dispatch rules, contractual flexibility and plant operating constraints can have economic value comparable with major new investment decisions.

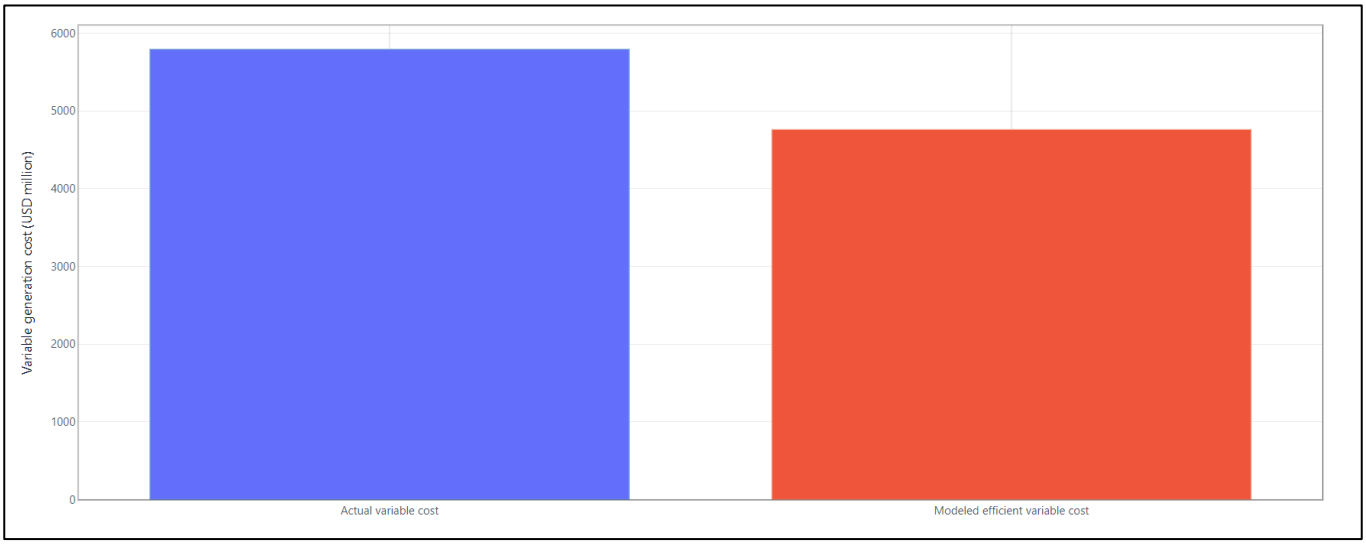


Figure 15.2. Historical variable generation cost: actual versus modelled efficient dispatch, 2018/19.

Source: World Bank/ESMAP (2020), Planning for Efficient Dispatch, Table 4-1. Historical model comparison.

15.4 Chronological-model evidence boundary

A current auditable 8,760-hour model still requires hourly demand/net load, solar and wind output, reservoir inflows and storage constraints, plant availability and outages, unit heat rates and fuel costs, commissioning/retirement dates, reserve requirements, nodal or corridor transfer limits and behind-the-meter generation. Public solar and wind measurement resources have been identified, and historical hourly PLEXOS studies demonstrate the required method, but Chapters 15-17 do not fabricate missing current profiles. The companion evidence database therefore contains a readiness matrix and preserves full chronological optimization as a subsequent decision gate.

16. Storage and Flexibility

16.1 Reserves, ramp rates and flexibility value

The same World Bank dispatch study quantifies the economic importance of ramping flexibility. The Grid Code/study secondary reserve requirement was 220 MW. Actual average secondary reserve provision was about 164 MW, compared with about 218 MW in the modelled case. When identical reserve quantities were tested under contractual PPA ramp rates versus more representative benchmark ramp rates, modelled annual reserve cost fell from about USD 93.1 million to USD 12.3 million, a difference of USD 80.8 million per year. The result does not establish a present-day saving of that

amount, but it demonstrates that operating flexibility has a measurable economic value and should be treated as a system resource.

16.2 Storage is a service stack, not simply another generator

Battery energy storage and pumped storage can shift energy, provide reserves, reduce curtailment, support ramping, defer selected network upgrades and improve resilience. Their economics therefore cannot be compared with solar, wind or hydro using generator LCOE alone. The appropriate model is LCOS plus a service-revenue or avoided-cost stack that includes charging cost, round-trip losses, degradation, cycling, replacement, capacity value, ancillary services, curtailment recovery and locational grid value.

Accordingly, the storage quantities in Chapter 24 are retained only as stress-test variables. Procurement quantities should emerge from chronological and locational modelling rather than from a fixed percentage of peak demand.

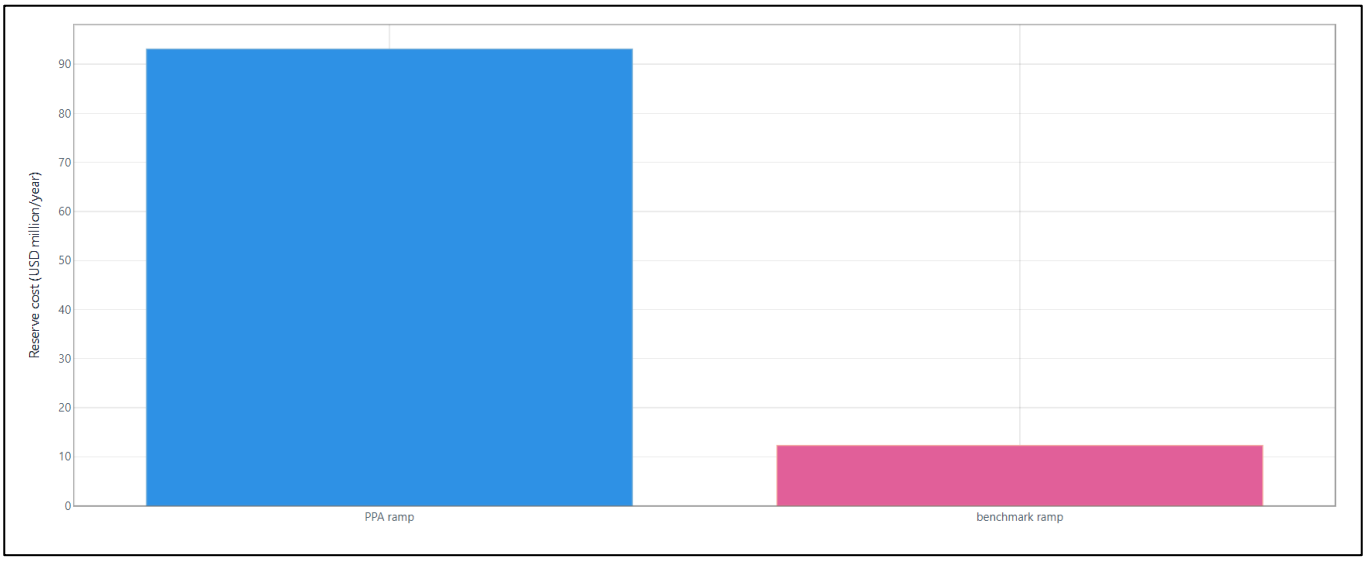


Figure 16.1. Modeled reserve cost under PPA and benchmark ramp-rate assumptions.
Source: World Bank/ESMAP (2020), Planning for Efficient Dispatch. Historical 2018/19 model evidence.

16.3 Where storage is most likely to create value

The strongest screening locations are not necessarily the places with the largest renewable resource. Southern wind corridors may value storage where transmission or stability constrains output; Balochistan hybrid parks may value storage where it improves long-distance transmission utilization; hydro nodes may support pumped-storage opportunities; and dense Punjab/Sindh load centres may value batteries for peak reduction, reliability and network deferral. The specific MW/MWh and duration should be chosen by the avoided system cost at each location.

17. Efficiency, Demand Response and Electrification

17.1 Demand flexibility as an energy resource

The wide spread between Pakistan's annual maximum, average and minimum load means that reducing or shifting peak demand can avoid costs that would otherwise be met by new generation, fuel, reserves or network reinforcement. Chapter 24 already shows that an efficiency-oriented demand pathway materially lowers future capacity requirements. Chapters 15-17 add the chronological and system-integration evidence needed to interpret that result: the value of a kilowatt-hour saved or shifted depends strongly on when and where it occurs.

17.2 Priority demand-side applications

Table 17.2. Priority demand-side interventions by sector and the system value to be tested.

Demand segment	Potential intervention	System value to test
Households	Efficient cooling/appliances; smart tariffs; rooftop-PV coordination	Lower evening peak, affordability and reduced distribution stress.
Industry	Efficiency, demand response, thermal storage, captive-resource coordination	Reliability, power quality and peak shifting.
Agriculture	Efficient pumps; solar-pump controls; timed pumping	Energy savings must be coupled with groundwater safeguards.
Transport	Managed EV charging	Shift charging to low-cost hours and avoid adding to evening peak.
Buildings / heat	Efficient cooling/heating; thermal storage	Reduce peak electricity and enable sector coupling.

Demand-side measures should enter Brill-Viz Economics as avoided-cost projects with CAPEX, programme administration, measured persistence, rebound risk and the value of avoided generation or network investment. The evidence base does not yet contain a Pakistan marginal efficiency supply curve, so these opportunities remain a quantified modelling workstream rather than an assumed free resource.

17.3 Official efficiency-policy and institutional implementation benchmark

The Year Book 2023-24 makes efficiency and conservation a concrete policy workstream rather than a generic recommendation. It records the NEEC Policy 2023 and NEEC Action Plan 2023-2030, with 29 priority actions and a stated cumulative saving target of 9 Mtoe by 2030, alongside a 35 MtCO2e emissions-reduction target. The Action Plan maps about US$8 billion of investment potential and US$6.4 billion of cumulative financial savings at 2022 prices, while appliance MEPS and labeling and the Energy Conservation Building Code 2023 provide implementation mechanisms. These are policy targets and modelled potentials, not realized savings, and are therefore kept separate from observed system performance (Ministry of Energy (Power Division), 2024).

The FY2025-26 budget records are used only as evidence of institutional implementation capacity. The submitted forms show gross budget estimates of Rs 427.0 million for Power Division administration and Rs 283.336 million for NEECA, with the latter tagged to energy-efficiency and conservation activities. These are administrative and operating budget provisions, not a national energy-project investment envelope, and they are excluded from technology CAPEX, LCOE and portfolio-investment comparisons (Ministry of Energy (Power Division), 2025).

PART VI - ECONOMICS AND INVESTMENT

18. Project Economics Evidence Base and Common Economic Framework

18.1 Why economics must begin with traceable project evidence

The synthesis will not compare technologies by quoting one headline LCOE from each source. Project economics will be reconstructed from traceable capital cost, development cost, financing, operating cost, generation, tariff and lifetime assumptions. Where a value is drawn from an actual Pakistani project, its project vintage and tariff regime are retained. Where a value comes from an international benchmark, it is labelled as a benchmark. Where a value is assumed for a scenario, it will be labelled as an assumption and sensitivity-tested.

Chapter 18 establishes the first common Pakistan project-economics evidence table, retaining original cost and tariff definitions, project vintage and evidence class before normalization.

18.2 Selected Pakistan project evidence

Table 18.1. Selected Pakistan project-economics evidence assembled for comparative analysis.

Project	Capacity	Reported project cost	Derived cost	Reported tariff	Generation / CF evidence	Source
Karot hydro	720 MW	USD 1,698m	USD 2,358/kW	7.6152 USc/kWh	3,174 GWh/yr	PPIB (PPIB, 2026; PPIB, n.d.)
Suki Kinari hydro	884 MW	USD 1,963m	USD 2,221/kW	5.5467 USc/kWh	3,048 GWh/yr	PPIB (PPIB, 2026; PPIB, n.d.)
Quaid-e-Azam solar	100 MW	USD 151.43m	USD 1,514/kW	14.9667 USc/kWh	Not in source page	PPIB (PPIB, n.d.)
Hydro China Dawood wind	49.5 MW gross	USD 122.94m	USD 2,484/kW	13.5244 USc/kWh	CF 32.7%	PPIB (PPIB, n.d.)
Engro Powergen Thar	660 MW	USD 995.4m	USD 1,508/kW	PKR 8.255/kWh	Not used here	PPIB (PPIB, 2022)
Safe Solar petition case	10 MW	USD 9.275m	USD 928/kW	5.48 USc/kWh requested	18.7 GWh/yr	NEPRA petition (Safe Solar Power, 2020)

The table intentionally exposes the normalization problem. These projects have different commissioning years, financing arrangements, tariff structures, cost definitions, technologies and currencies. The numerical values therefore cannot be interpreted as a current technology ranking without converting to a common real base year, separating generation from transmission costs, and reconciling tariff components.

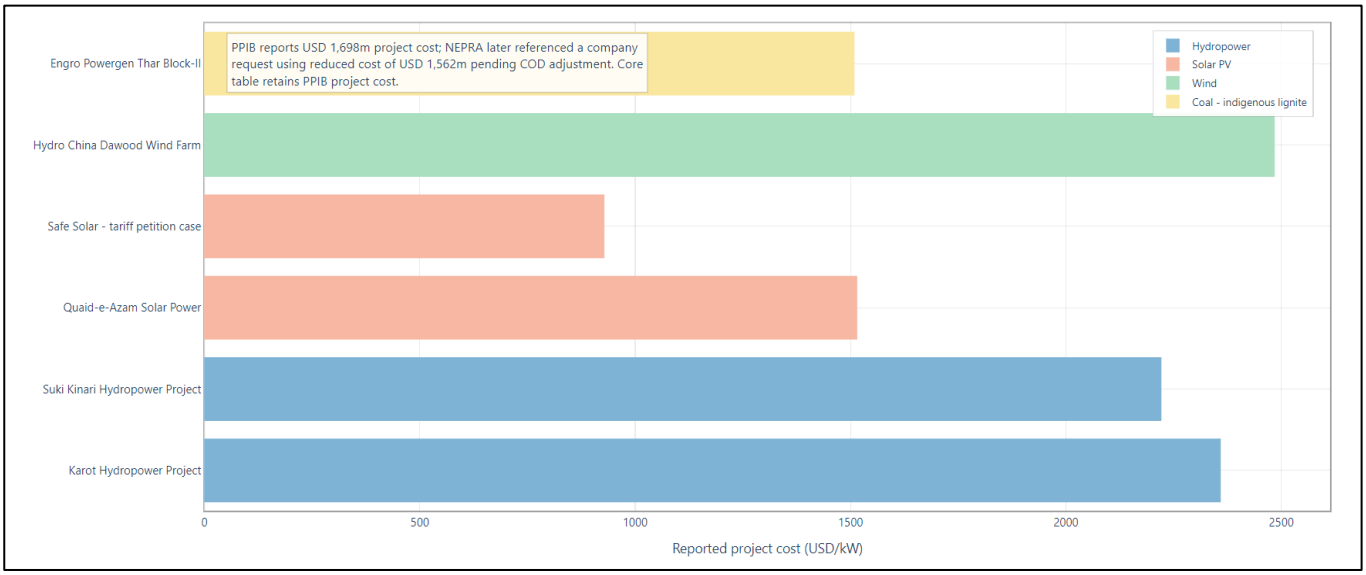


Figure 18.1. PPIB/petition-reported project cost per kW for selected Pakistan generation projects.

Sources: PPIB and NEPRA evidence (PPIB, 2026; PPIB, n.d.; PPIB, 2022; Safe Solar Power, 2020). Different project vintages and cost definitions mean this is descriptive evidence, not a normalized cost ranking.

18.3 What an actual project cost contains

The detailed Safe Solar tariff petition illustrates why a single “plant cost” number is insufficient. Its submitted USD 9.275 million total project cost included USD 7.501 million EPC cost plus development cost, operating fixed assets and land, capitalized degradation, insurance during construction, additional post-LOS project cost, financial fees and interest during construction. The same filing reports 18.7 GWh/year, a 20.5% capacity factor, project O&M of USD 12,000/MW and a requested levelized tariff of 5.48 US cents/kWh. (Safe Solar Power, 2020)

Chapter 18 uses the evidence register to distinguish sourced project inputs from modelling assumptions and unresolved gaps.

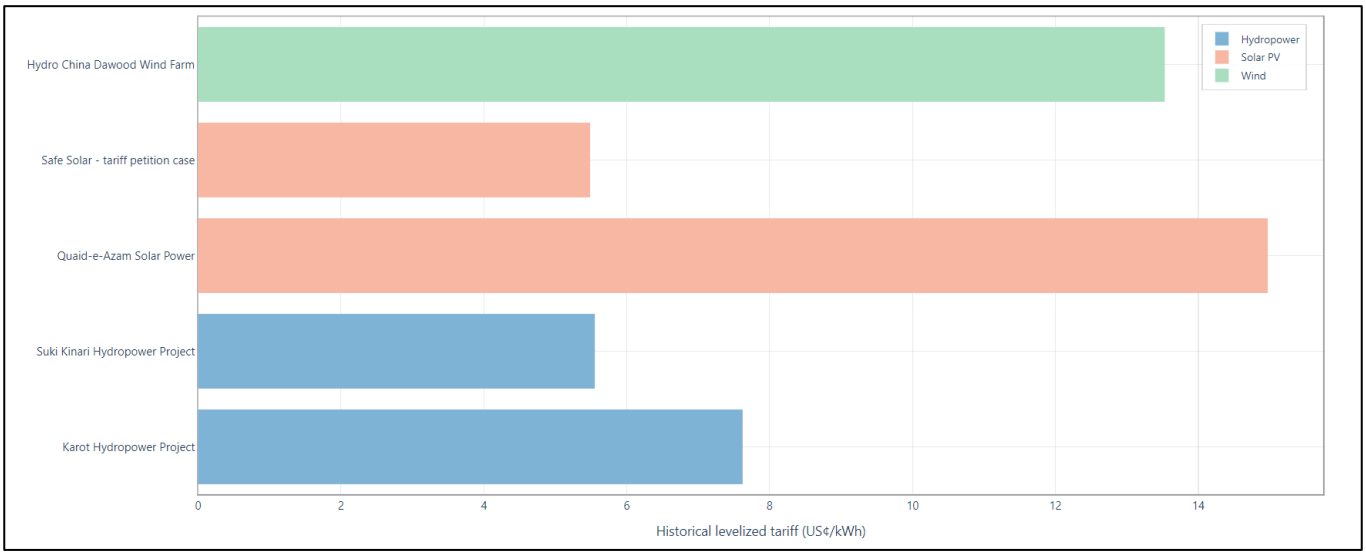


Figure 18.2. Selected historical levelized tariffs reported in US cents/kWh.

Sources: PPIB project pages and NEPRA petition (PPIB, n.d.; PPIB, 2022; Safe Solar Power, 2020). Values are shown on their source-vintage basis and are not inflation-, FX- or tariff-structure-normalized.

18.4 Geothermal economics: benchmark before model

For geothermal, Pakistan currently lacks a project-specific commercial cost base. The economics therefore begin with global operating benchmarks and a separate local resource-validation model. IRENA's 2024 weighted averages provide a starting reference of USD 4,015/kW total installed cost, USD 0.060/kWh LCOE and 88% capacity factor, while Türkiye and New Zealand demonstrate much lower cost outcomes under favorable resource, supply-chain and financing conditions. (IRENA, 2025)

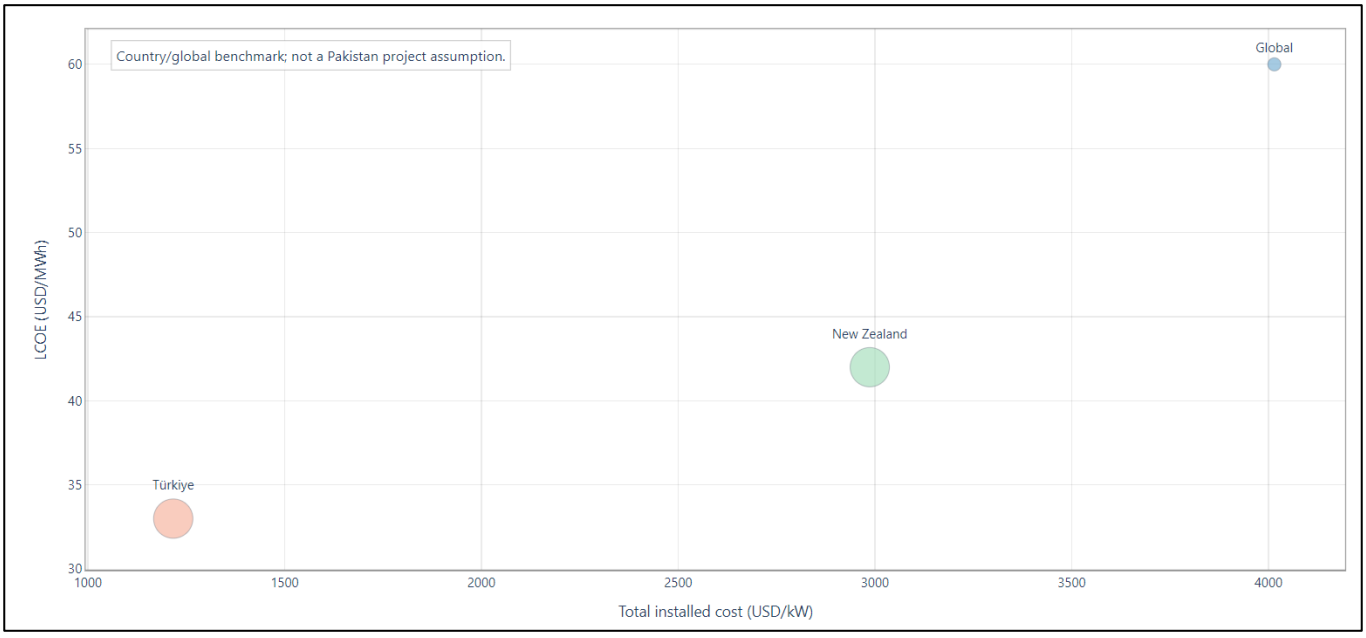


Figure 18.3. Selected 2024 geothermal cost-performance benchmarks.

Source: IRENA Renewable Power Generation Costs in 2024 (IRENA, 2025). Bubble size represents capacity factor. Country values are analogues, not Pakistan assumptions.

The correct Pakistan approach is therefore a two-stage model. Stage A is exploration and resource-validation economics, where success probability, geoscience cost, drilling cost and risk-sharing determine expected monetary value. Stage B is development economics, entered only after a resource case is established, where wells, surface plant, grid connection, cooling, reinjection, make-up wells, O&M, financing and tariff are modelled over project life.

The cash-flow architecture allows cross-technology comparison without pretending that every technology has identical cost drivers. Fuel-price and FX exposure dominate some gas/LNG cases; hydrology and civil works dominate hydro; drilling success and make-up wells matter for geothermal; and variable renewable projects require explicit treatment of curtailment, grid connection and, when required, storage or firming.

18.5 Common cash-flow architecture for Brill-Viz Economics

Table 18.2. Common cash-flow architecture to be implemented in Brill-Viz Economics.

Cash-flow block	Typical contents	Timing
Development / pre-FID	Studies, permits, land, geoscience, feasibility, development overhead	Years -N to 0
Resource development	Exploration, confirmation, production and injection wells; hydro civil works; mine/resource infrastructure	Construction
Plant EPC	Generation equipment and balance of plant	Construction
Grid / site infrastructure	Transmission/interconnection, substations, roads, water systems	Construction
Financing	Fees, interest during construction, debt drawdown/repayment, equity contributions	Construction + operations
Operating revenue	Net generation x tariff/PPA; heat sales; other contracted revenues	Operations
Operating costs	Fixed O&M, variable O&M, fuel/feedstock, water, insurance, royalties, replacement and make-up wells	Operations
Tax / working capital	Taxes, duties, receivables/payables and reserve accounts where material	Operations
Terminal	Decommissioning/rehabilitation, residual value or transfer under concession	End of life

18.6 Investor-Consumer Bankability Window

A central analytical contribution of the synthesis will be the Investor-Consumer Bankability Window. The investor floor is the tariff or revenue level required to satisfy target equity return, debt service and risk conditions. The consumer/system ceiling is the highest economically rational delivered price after accounting for the cost of alternative supply, capacity/reliability value, fuel-import and foreign-exchange savings, integration cost, water constraints and other system effects. A project is naturally bankable only when the investor floor is at or below the consumer/system ceiling.

If the investor floor is above the system ceiling, the model will quantify the gap rather than hide it. The gap can then be tested against specific interventions: exploration-risk insurance, concessional debt, grants, lower-cost drilling, longer debt tenor, FX-risk mitigation, local-content development, different cooling technology, a smaller pilot, or rejection of the study. This makes subsidy and de-risking requirements explicit and comparable.

18.7 Calculation scope and evidence limits

The evidence base can already reproduce several published project-cost and tariff comparisons, but full DCF and bankability analysis remains restricted to cases with sufficiently complete financing, O&M, tax and indexation inputs.

This is a deliberate strength rather than an incompleteness to be hidden. The synthesis will run full economics only when the provenance of each key input is explicit. Sensitivity cases can be run earlier, but they will be labelled as scenarios rather than project forecasts.

18.8 Project-economics synthesis

Public project documents are sufficient to establish a defensible cost and tariff evidence base, but not yet a single normalized ranking. Further economics refinement requires COD-adjusted project costs, actual annual generation, tariff-component histories, financing terms, grid/interconnection expenditure and technology-specific water/O&M evidence. Where these inputs are sufficiently complete, Brill-Viz Economics can calculate NPV, IRR, MIRR, payback, LCOE, breakeven tariff, Monte Carlo risk and the Investor-Consumer Bankability Window on a common basis.

18.9 Generation cost is not delivered system cost

The resource-specific synthesis adds evidence on utilization, resource quality, water and grid constraints that should be carried into the economic comparison rather than treated as external commentary.

The Brill-Viz economics cases therefore retain at least two cost layers where relevant: the published or observed project evidence and the normalized modelling case used for sensitivity or bankability analysis.

18.10 Economic case basis and comparator-derived prospective analysis

The economics architecture now distinguishes four case bases so that published evidence and prospective policy modelling cannot be confused: observed/existing Pakistan projects; Pakistan proposed projects with sourced inputs; comparator-derived Pakistan scenarios; and illustrative or screening cases. Existing assets are evaluated primarily on point-forward economics, while new/proposed projects are evaluated on full-life economics only when their capital, operating, financing and revenue assumptions are explicit.

Comparator-derived scenarios are used only where Pakistan-specific new-build evidence is incomplete. A recent international benchmark or functional comparator supplies a transparent starting point; Pakistan-specific resource quality, project scale, localization/import content, grid/interconnection, site development, water/environment, construction, financing, FX and contingency assumptions are then applied explicitly. The resulting value remains a scenario, not an observed Pakistan cost.

The companion economics workbook carries Favourable/Best-Practice, Base/Realistic and Conservative/Stress cases. These scenario labels are analytical bands rather than forecasts. Tariff is normally treated as an output through the investor-floor calculation for a new project; an entered tariff is instead a test of whether the project can satisfy NPV, IRR and DSCR conditions.

Table 18.3. Economic case-basis discipline used for the synthesis, Brill-Viz input workbook and policy analysis.

Case basis	Primary input source	Economic use	Interpretive boundary
Observed / existing	Pakistan project, plant, tariff and operating evidence	Historical reconstruction and point-forward remaining-life economics	Historical CAPEX is not re-spent in the current year.
Pakistan proposed / sourced	PC-I, tariff filing, appraisal, financing or project documents	Full-life DCF where core CAPEX/O&M/finance/revenue inputs close	Unsupported fields remain blank or scenario-tagged.
Comparator-derived Pakistan scenario	Recent international benchmark + explicit Pakistan adjustments	Prospective new-build screening and policy sensitivity	Not an observed Pakistan cost or investment offer.
Illustrative / screening	Transparent assumptions used to test mechanisms or data gaps	Sensitivity, stress testing and research design	Not project-decision or financial-close grade.

19. Common Comparative Economics and Bankability Cases

19.1 Purpose: from headline cost to evidence-normalized economics

Chapter 19 does not force technologies into one metric when their cost drivers differ materially; fuel exposure, hydrology, drilling risk, storage duration and capacity value remain explicit.

The common-case set deliberately mixes three evidence classes that must remain visibly different: commissioned Pakistan project evidence, approved/development project evidence, and international or modelled benchmarks. Commissioned cases are useful for reconstructing historical cost architecture; benchmarks provide technology context; modelled studies test system concepts. None is automatically a current investment offer.

19.2 Common evidence-normalized cases

Table 19.1. Common evidence-normalized economics cases assembled for Chapter 19.

Technology	Case	Scale	Cost evidence	Published price metric	Comparative-economics status
Solar PV	Safe Solar petition	10 MW	USD 9.28m	5.48 USc/kWh requested	Partial; petition, not final tariff
Wind	HydroChina Dawood	49.5 MW	USD 122.94m	13.5244 USc/kWh	Partial; historical project
Hydro	Karot	720 MW	USD 1,698m	7.6152 USc/kWh	Partial; actual multi-year generation still needed
Geothermal	IRENA global 2024	-	USD 4,015/kW	6.0 USc/kWh LCOE	Benchmark only; not Pakistan project
Nuclear	C-5 PC-I	1,100 MW gross	PKR 1,047,988.84m	No tariff used	Partial; tariff/finance/evacuation gaps
Thar coal	Engro Powergen Thar	660 MW	USD 995.4m	8.5015 USc/kWh	Partial; current indexation/fuel/water gaps
RLNG CCGT	PTPL / Trimmu	1,263.2 MW	USD 801.84m	6.5374 USc/kWh	Partial; current fuel/FX/O&M gaps
RFO / liquid fuel	Nishat Power	200 MW gross / 195 MW net	USD 203.95m historical reference cost	36.8213 PKR/kWh Jan-2026 FCC	Partial; strong current fuel evidence, but FCC is not the full tariff and current O&M/remaining finance are incomplete
Battery storage	4-h utility Li-ion ATB	-	Not imported as Pakistan CAPEX	No LCOS assigned	Benchmark incomplete
Solar-wind-HVDC	Chagai study case	~7 GW VRE	Modelled system	6.46-6.66 USc/kWh	Scenario only; includes evacuation concept

Sources: companion evidence database (PPIB, 2026; PPIB, n.d.; PPIB, 2022; Safe Solar Power, 2020; NEPRA, 2026; PAEC, 2024; Planning Commission, 2024; NREL, 2024; IRENA, 2025; World Bank, 2024). Values retain their original evidence class and project vintage.

19.3 Capital intensity is informative, but it is not a ranking by itself

The reported project-price evidence shows large differences in capital intensity. Pakistan H-class RLNG CCGT projects were constructed at much lower reported USD/kW than large hydro or early wind projects, while coal and solar occupy intermediate positions in this historical sample. This does not mean the lowest-CAPEX technology is the cheapest source of energy. Fuel cost, capacity payments, utilization, project life, resource risk, financing, water and grid requirements can reverse a simple capital-cost ranking. (PPIB, 2026; PPIB, n.d.; PPIB, 2022; Safe Solar Power, 2020)

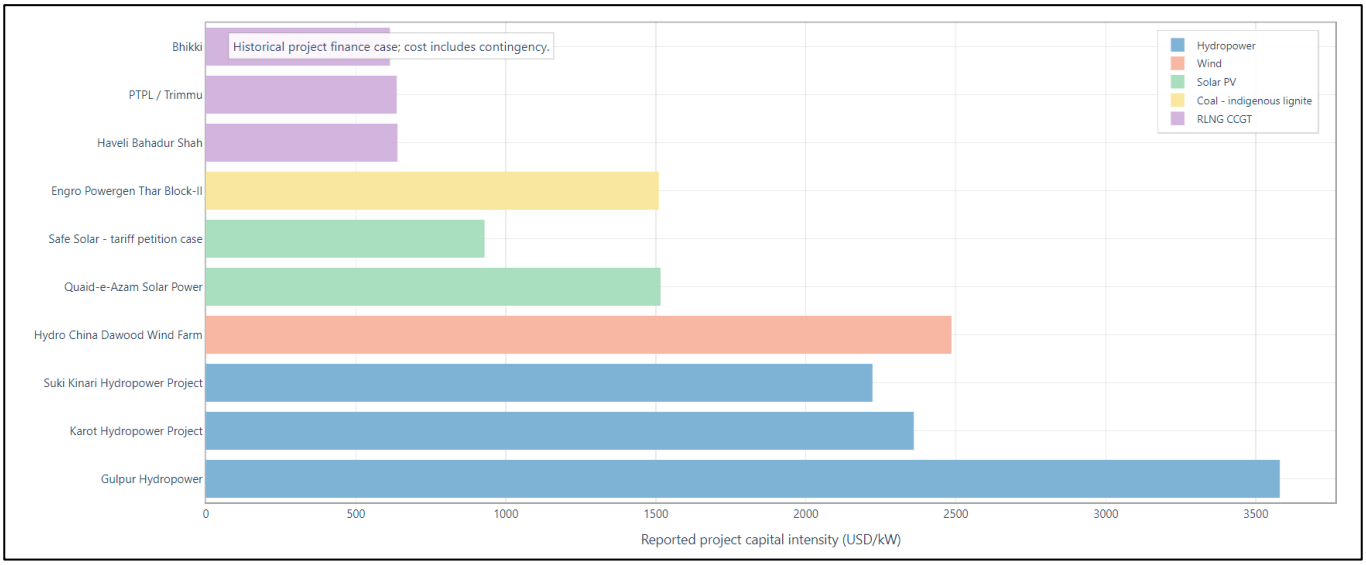


Figure 19.1. Selected Pakistan generation projects: reported project capital intensity.

*Sources: PPIB, NEPRA filing and World Bank/IFC project evidence (PPIB, 2026; PPIB, n.d.; PPIB, 2022; Safe Solar Power, 2020; World Bank Group et al., 2016). *Safe Solar is a tariff-petition case, not a final approved-cost benchmark.*

19.4 Historical project tariff versus capital intensity

Accordingly, project vintage and tariff status are mandatory fields before normalization. A historical levelized tariff is not relabelled as a current payable tariff or a present-day new-build cost.

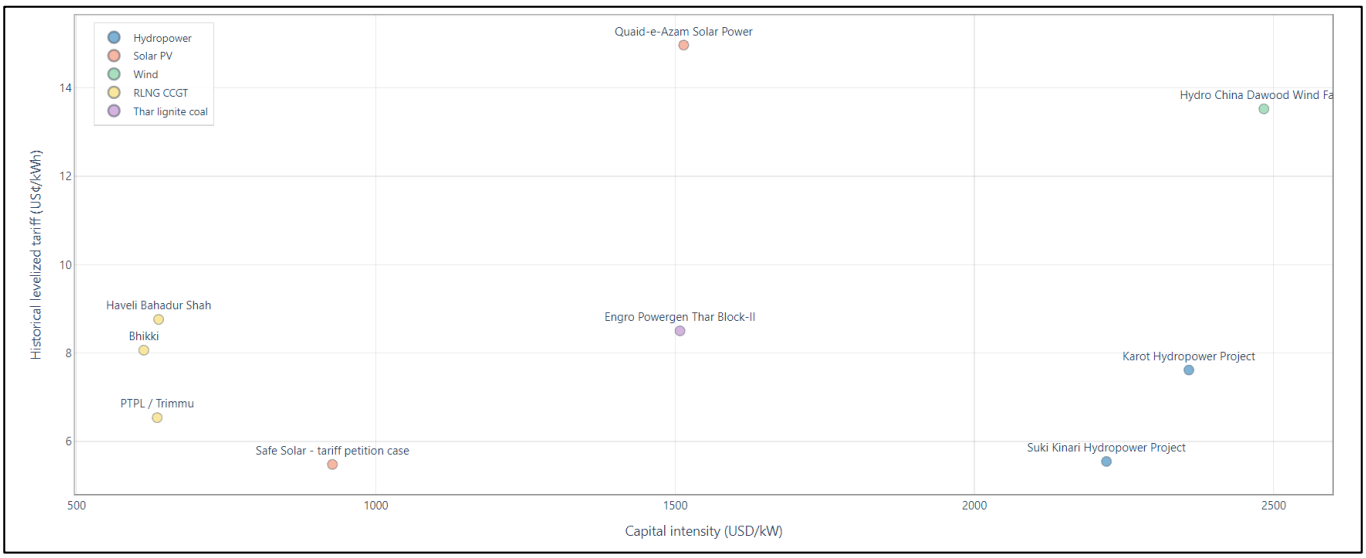


Figure 19.2. Historical published tariff versus reported project capital intensity.

Sources: PPIB project pages and NEPRA tariff-petition evidence (PPIB, 2026; PPIB, n.d.; PPIB, 2022; Safe Solar Power, 2020). Tariffs are historical/project-specific and are not normalized current payable rates.

19.5 RLNG CCGT: low capital intensity, high fuel and foreign-exchange exposure

Table 19.2. Selected Pakistan RLNG CCGT projects and a Thar-coal comparator.

Project	Gross MW	Project cost USDm	Derived USD/kW	Levelized tariff USc/kWh	Net efficiency %	Availability %	Debt:Equity	COD
Bhikki	1,180.13	722.6	612	8.064	61.59	92	75:25	2018
Haveli Bahadur Shah	1,230.54	784.0	637	8.760	62.20	92	70:30	2018
PTPL / Trimmu	1,263.2	801.84	635	6.5374	61.16	92	75:25	2023
Engro Thar (coal comparator)	660	995.4	1,508	8.5015	-	-	75:25	2019

Source: PPIB project pages (PPIB, n.d.). Project-page levelized tariffs are historical contract metrics, not current indexed energy costs.

The three RLNG plants show a consistent engineering pattern: approximately USD 612-637/kW reported project price, net efficiencies around 61-62%, and 92% annual availability on the PPIB pages. Their economic weakness is not necessarily plant CAPEX; it is fuel and foreign-exchange exposure plus the system cost of paying for available capacity when dispatch is low. At the national level, the Pakistan Economic Survey reports a petroleum-group import bill of about US$11.25 billion during July-March FY2026, with LNG alone still around US$1.9 billion despite a 29.7% year-on-year decline. NEPRA reports that thermal plants as a class operated at only 42.5% utilization in FY2024-25 and identifies imported RLNG, RFO and imported coal as important drivers of energy purchase cost. Brill-Viz economics should therefore stress-test RLNG cases against fuel-price, freight and FX shocks rather than treat a historical levelized tariff as a stable future cost (PPIB, n.d.; NEPRA, 2026; Government of Pakistan, 2026).

19.6 RFO and liquid-fuel thermal assets: current fuel evidence is strong, full project economics remain partial

RFO is treated as a separate thermal-fuel case because the cost drivers differ from RLNG and coal. The representative Nishat Power case now carries current local-currency fuel price, direct fuel-cost component, petroleum/climate levies, FX sensitivity, realized utilization, historical project-cost architecture and an explicit existing-asset flag in the Brill-Viz economics dataset. The historical NEPRA reference project cost of about US$203.95 million and 75:25 debt-equity structure are retained only as vintage-specific project architecture, not as a 2026 replacement cost or remaining debt balance (NEPRA, 2007).

This separation is analytically important. A current regulatory fuel-cost component can be used to test fuel, levy, logistics and FX exposure, while an all-in DCF additionally requires current capacity and energy charges, fixed and variable O&M, taxes, remaining contract life, financing and expected dispatch. Brill-Viz therefore permits screening and probabilistic stress analysis for the current RFO case without converting incomplete inputs into a financial-close result.

19.7 Nuclear: operating performance is strong evidence; C-5 cost is not yet a tariff

This synthesis retains the original evidence class for every project and benchmark so that reported observations, derived calculations and modelling assumptions remain distinguishable.

The Brill-Viz economics model therefore does not infer missing finance, tax, O&M or fuel assumptions from unrelated projects. Unsupported inputs remain blank or are explicitly labelled as scenarios.

19.8 System economics: capacity cost and energy cost must be separated

NEPRA's FY2024-25 performance report provides the clearest reason why plant-level LCOE alone is insufficient for Pakistan. Total power purchase cost, excluding Iranian imports, was PKR 2,943.214 billion. Capacity Purchase Price

accounted for 61% of the total and Energy Purchase Price 39%; the reported average components were PKR 14.3/kWh and PKR 9.0/kWh respectively. Overall thermal utilization was 42.5% and renewable utilization 36.6% (NEPRA, 2026).

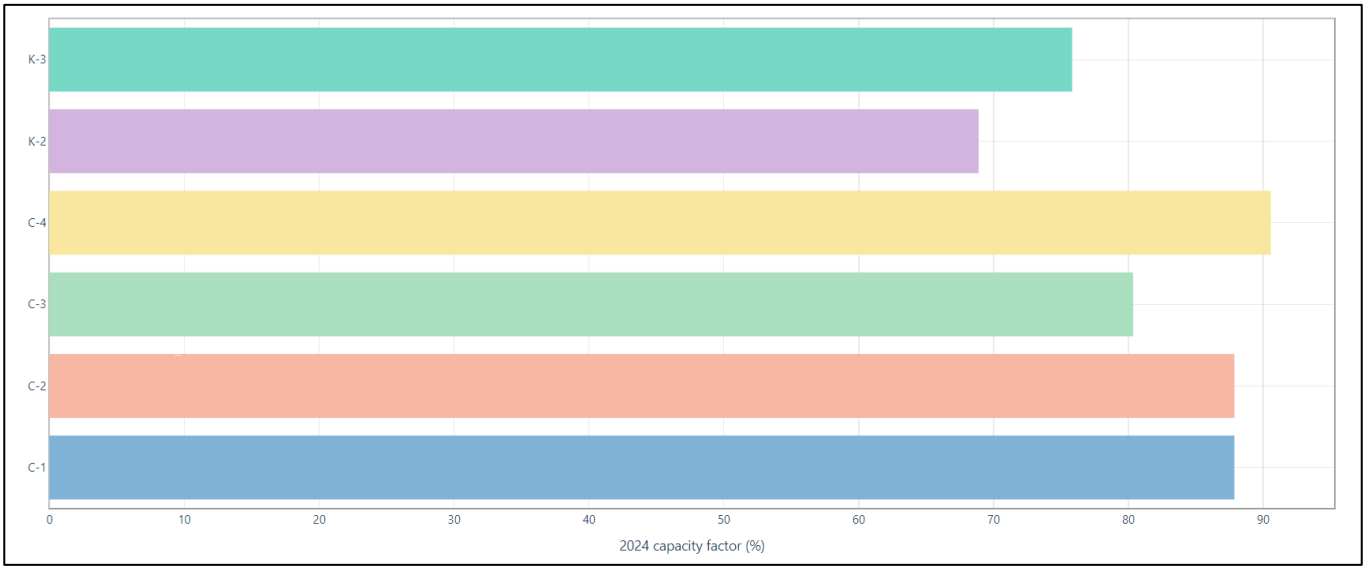


Figure 19.3. Pakistan nuclear power units: reported capacity factor, 2024.

Source: Pakistan Atomic Energy Commission (PAEC, 2024).

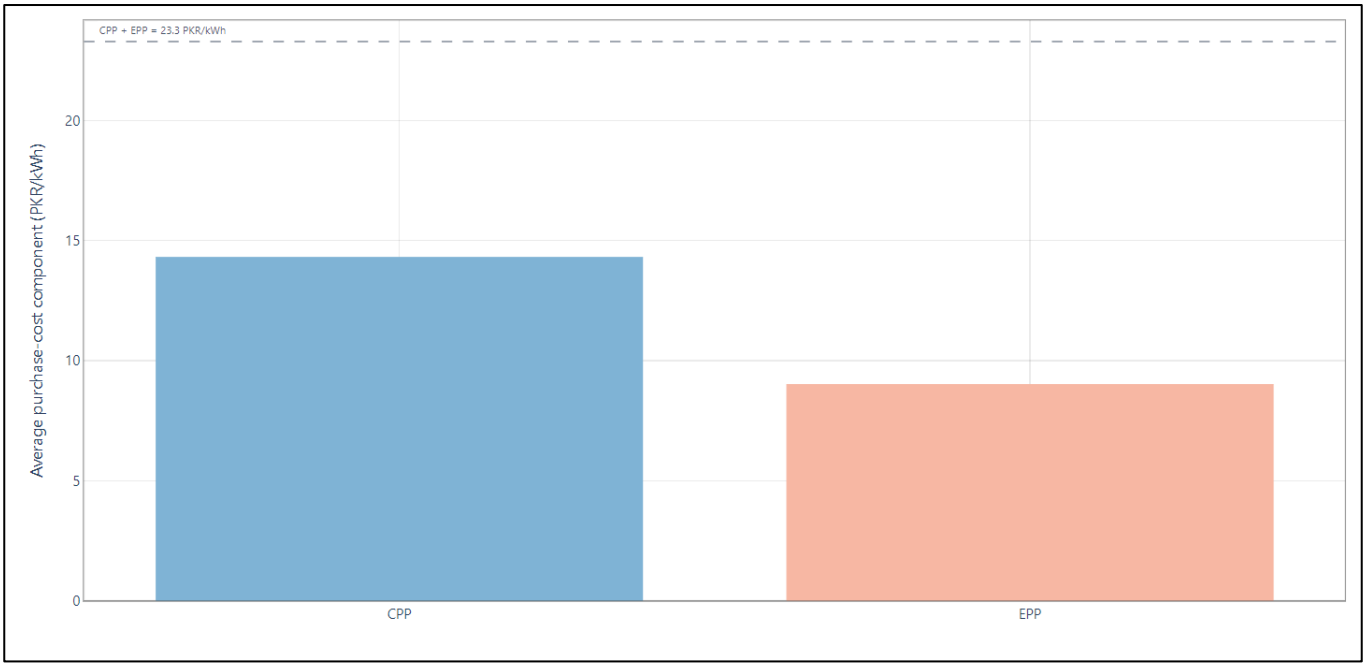


Figure 19.4. Pakistan average power-purchase cost components, FY2024-25.

Source: NEPRA, Performance Evaluation Report of Operational Power Plants FY2024-25 (NEPRA, 2026). These are purchase-cost components, not the consumer retail tariff.

The comparative economics framework therefore carries project cost, tariff, utilization, financing and system-value evidence together rather than ranking projects on one headline number.

19.9 Storage and hybrid systems require different economics

Battery storage is not treated as a generator with a conventional fuel-free LCOE. The 2024 ATB assumes 85% round-trip efficiency, a 15-year life, about one cycle per day for a four-hour system (16.7% capacity factor) and fixed O&M equal to 2.5% of capital cost, including augmentation. A Pakistan storage case still requires sourced CAPEX, charging-energy cost, degradation/replacement profile, grid connection and a revenue or avoided-cost stack before LCOS, NPV or IRR can be defended. (NREL, 2024)

The Balochistan hybrid evidence illustrates the same system principle from the opposite direction. The World Bank study's modelled Chagai case combines wind, solar and long-distance evacuation and reports a modelled PPA range of about 6.46-6.66 US cents/kWh for the larger cost-optimal concept. That value is useful precisely because evacuation is part of the concept, but it remains a model result rather than an awarded tariff or operating cash flow. (World Bank, 2024)

19.10 Economics readiness and the threshold for full DCF

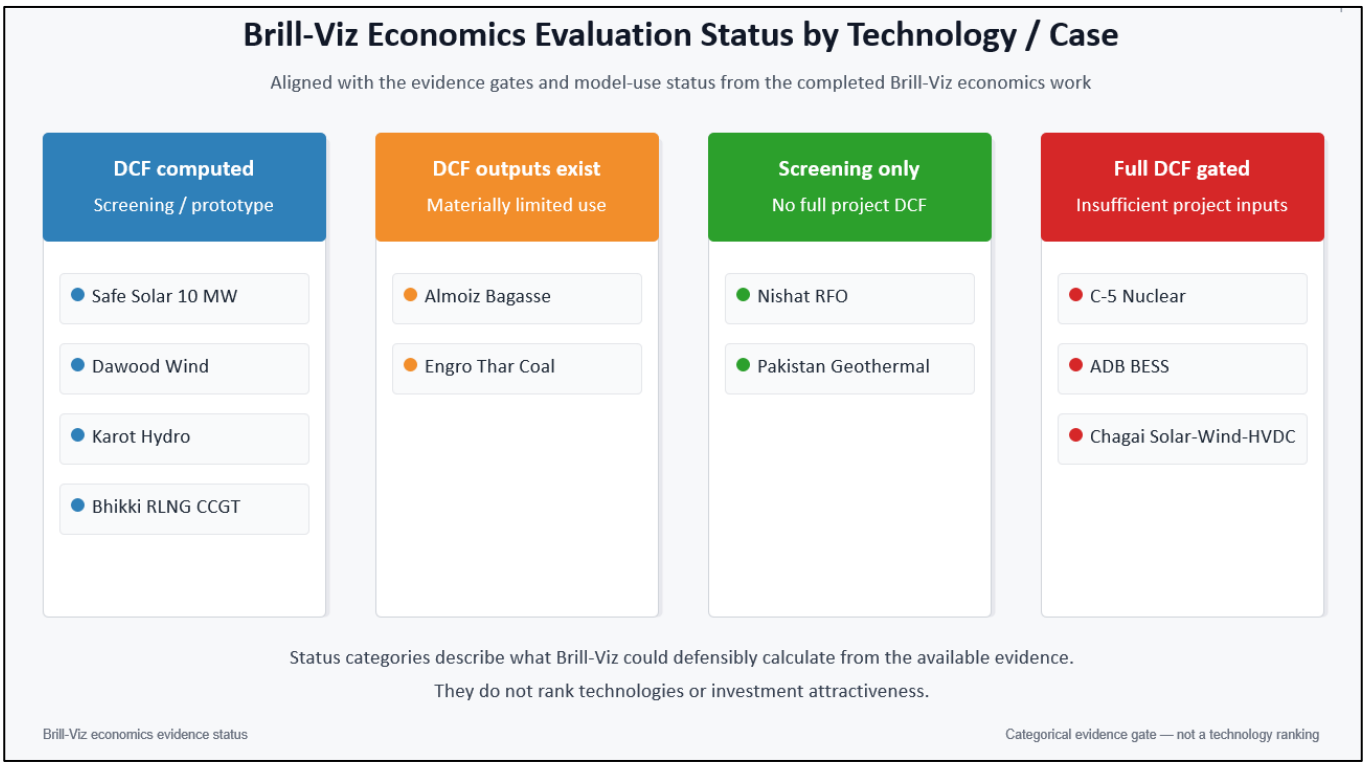


Figure 19.5. Economics evidence readiness by technology/case.

Source: Companion evidence database, economics-readiness matrix. This is an internal completeness score for required DCF inputs, not a technology merit or investment score.

The readiness matrix shows why a single universal DCF would still be misleading. Solar has the most complete public cost architecture in the current database because the Safe Solar filing includes detailed cost and O&M structure. Wind, hydro, Thar coal, RLNG and the new RFO case have several strong project or operating-evidence blocks but still lack at least some current O&M, financing, water/environment or dispatch inputs. Pakistan geothermal and C-5 nuclear remain much less complete economically for different reasons, while battery storage lacks a Pakistan-specific total installed CAPEX and revenue stack. These are evidence gaps, not zeros.

Brill-Viz Economics has now been run against the final dual-view economics workbook. The full-life/investment view was used for Safe Solar, Hydro China Dawood wind, Karot hydropower, Bhikki RLNG CCGT, Engro Powergen Thar, Almoiz bagasse and the Pakistan geothermal screening case; the point-forward view was used for commissioned-asset operating screens, including Dawood, Karot, Bhikki, Engro, Almoiz and Nishat RFO. Only Safe Solar carries a Full-DCF

evidence gate of Yes. The other project runs remain screening-only or explicitly gated because current O&M, financing, tariff, fuel/feedstock, resource or contract inputs are incomplete. Point-forward cases are not interpreted as project-return DCFs when sunk CAPEX, debt service or current revenue/O&M evidence is absent.

19.11 Comparative economics synthesis

The completed Brill-Viz validation runs confirm the value of separating historical/full-life reconstruction from current point-forward economics. The outputs below are therefore reported as evidence-classed screening results, not as a technology ranking or investment recommendation. Where a run is materially biased by unresolved zero O&M, fuel/feedstock, financing or revenue inputs, the numerical return metrics are deliberately withheld from headline publication use.

Table 19.5. Brill-Viz full-life screening outputs selected for publication use.

Case / view	Selected deterministic result	Bankability / uncertainty signal	Publication treatment
Safe Solar - full-life	Project NPV -US$0.246m; project IRR 7.67%; equity IRR 8.38%; LCOE US$56.13/MWh	DSCR floor US$73.13/MWh; P(NPV>0) 37.7%	Full-DCF gate Yes; prototype only, not investment-grade.
Dawood wind - full-life	Project NPV US$12.92m; IRR 10.29%; LCOE US$99.70/MWh	DSCR floor US$145.82/MWh; P(NPV>0) 74.3%	Historical reconstruction; current O&M/tariff/remaining-finance gaps.
Karot hydro - full-life	Project NPV -US$563.33m; IRR 7.72%; LCOE US$112.05/MWh	Equity/DSCR floor US$140.53/MWh; P(NPV>0) 0%	Screening only; financing, current hydrology and tariff/tax structure incomplete.
Bhikki RLNG - full-life	Project NPV -US$299.01m; IRR 3.55%; LCOE US$86.48/MWh	DSCR floor US$95.56/MWh; P(NPV>0) 33.3%	Screening only; fuel, O&M, financing, capacity-payment and dispatch gaps remain.
Pakistan geothermal - screen	Project NPV -US$78.75m; IRR 7.50%; LCOE US$108.06/MWh	Equity floor US$139.24/MWh; P(NPV>0) 0%	Comparator-derived scenario; prospect/resource gate remains open.
Engro Thar - full-life	Calculated run retained for audit; headline return metrics withheld	Full-DCF gate No	Current mine/fuel, O&M, water/environment, finance and tariff structure incomplete.
Almoiz bagasse - full-life	Calculated run retained for audit; headline return metrics withheld	Screening only	Current O&M, feedstock opportunity cost, seasonality and steam/cogeneration value incomplete.

Source: final Brill-Viz Complete Economics PDF runs supplied for this study, 17 September 2026. Historical/full-life construction years in these reconstructions are normalized model years and are not presented as the projects' actual historical construction calendar. Point-forward Karot and Bhikki outputs are used as operating/current screens; Dawood, Engro and Almoiz point-forward zero-CAPEX outputs are not used as headline LCOE, IRR, DSCR or bankability-window results. Nishat RFO remains a fuel/dispatch screen because the current all-in tariff and O&M/remaining finance are not reconciled.

19.12 Prospective new-build screening cases

For prospective analysis, the workbook separates benchmark capital intensity from Pakistan operating/resource assumptions. The first screening set uses global 2024 renewable installed-cost benchmarks together with Pakistan screening capacity factors already used in the scenario framework. The capacity choices are modelling conventions, not national targets.

The Favourable/Base/Stress scenario bands vary capital cost, capacity factor, O&M and financing conditions transparently. Nuclear, BESS, hybrid, new thermal and other cases remain input-gated where the evidence base does

not support a defensible new-build cost. This prevents the economics engine from filling missing values with a generic technology preset and presenting them as project evidence.

Table 19.3. Initial benchmark-derived prospective cases carried in the economics workbook. Values are screening inputs, not Pakistan project quotations.

Technology	Benchmark CAPEX (USD/kW)	Pakistan screening CF	Illustrative model size	Use in prospective analysis
Solar PV	691	22.8%	100 MW	Benchmark-derived new-build screening; grid/ location still required.
Onshore wind	1,041	42.0%	100 MW	Resource/grid screening with curtailment and evacuation explicit.
Hydropower	2,267	45.0%	500 MW	Site-specific civil, hydrology and grid costs remain gating.
Geothermal	4,015	88.0%	50 MW	Stage-A exploration/resource risk precedes development DCF.
Bioenergy / bagasse	3,242	50.0%	30 MW	Feedstock/steam balance and seasonal utilization remain project-specific.

19.13 Prospective screening capital and energy envelopes

The companion economics workbook now consolidates the comparator-derived Favourable/Base/Stress envelopes into a compact screening summary. For the five benchmark-ready renewable/resource cases, the values below quantify how the stated scenario multipliers change indicative capital requirement and first-year energy at the illustrative model size. They are not LCOE, tariff, NPV or investment-offer results; those outputs remain gated by project-specific O&M, financing, revenue, tax, grid, water and technology inputs.

Table 19.4. Comparator-derived prospective screening envelopes used for policy-support analysis.

Technology / model size	Favourable-to-stress CAPEX envelope	Base screening CF	Base annual energy	Economic gate
Solar PV 100 MW	US$62.2-86.4m	22.8%	199.7 GWh	O&M/finance plus site/grid/curtailment remain explicit gates.
Onshore wind 100 MW	US$93.7-130.1m	42.0%	367.9 GWh	Current financing, evacuation and curtailment must be site-specific.
Hydropower 500 MW	US$1.02-1.42bn	45.0%	1,971 GWh	Civil works, hydrology/storage and grid cost remain site-specific.
Geothermal 50 MW	US$180.7-250.9m	88.0%	385.4 GWh	Exploration-risk EMV precedes development DCF; reservoir proof is mandatory.
Bioenergy / bagasse 30 MW	US$87.5-121.6m	50.0%	131.4 GWh	Feedstock opportunity cost, steam credit and seasonal utilization remain project-specific.

Source: companion economics workbook, sheets 19_Prospective_Econ_Cases and 20_Prospective_Screening_Summary. Scenario multipliers are explicit analytical assumptions; values are screening envelopes, not quoted Pakistan project prices or full DCF outputs.

20. Financing, Risk and Bankability

20.1 Bankability begins with risk allocation

Technology cost is only one component of bankability. Pakistan projects may face resource risk, construction and schedule risk, fuel and foreign-exchange exposure, hydrology, transmission delay, curtailment, offtaker/payment risk, refinancing risk, water availability and policy/regulatory uncertainty. The correct financing question is therefore not simply how to lower WACC, but which party can control each risk, which risks can be insured or shared, and which should remain with the developer.

Table 20.1. Principal energy-project bankability risks and preferred risk-allocation or mitigation tests.

Risk class	Examples	Preferred allocation / mitigation test
Resource	Geothermal productivity; hydro inflow; wind/solar resource	Measure before scale-up; stage-gate development; resource-risk insurance where justified.
Construction	EPC cost, delay, geotechnics	Fixed/limited-price EPC where bankable; contingency and performance guarantees.
Fuel / FX	RLNG, RFO/liquid fuels, imported coal, foreign debt	Test transparent indexation, explicit fuel/levy/freight/FX exposure, hedging feasibility and consumer incidence.
Grid / curtailment	Evacuation delay, congestion, dispatch	Connection milestones; compensation only where economically justified; locational planning.
Offtaker / tariff	Payment delay, indexation, demand risk	Credit enhancement, competitive procurement and realistic demand forecast.
Water / environment	Cooling water, reservoir impacts, emissions	Site-specific permits, water balance, mitigation and full compliance cost.

20.2 Macroeconomic financing context is not project WACC

For transparency, the companion evidence database records the State Bank of Pakistan M2M USD/PKR rate of 277.3228 on 11 September 2026 as a current conversion anchor. It is used only to translate selected historical US-cent/kWh values into an illustrative PKR/kWh screening comparison. A spot exchange rate, policy rate or sovereign yield is not a project WACC. Project discount rates must reflect debt tenor, currency, guarantees, taxes, inflation/indexation, construction risk and equity-return requirements.

20.3 De-risking should unlock good projects, not conceal bad economics

Geothermal illustrates the principle clearly. Türkiye and Indonesia show how public or concessional capital can absorb part of the early exploration risk, after which private capital can enter a better-defined resource. A Pakistan mechanism should use pre-agreed technical success criteria, staged commitments, transparent cost caps and developer co-investment. Similar logic applies to transmission enabling remote renewables: public infrastructure can be rational where it unlocks a lower total system cost, but the benefit must be demonstrated rather than assumed.

21. Portfolio Economics and the Investor-Consumer Bankability Window

21.1 From project LCOE to two-sided bankability

Chapter 21 formalizes the Investor-Consumer Bankability Window proposed earlier in the synthesis. The investor floor is the minimum tariff or revenue stream required to satisfy project debt service, operating obligations, taxes, replenishment or replacement costs and the required equity return. The consumer/system ceiling is the maximum economically rational payment given the cost of the next-best system alternative, avoided fuel imports and foreign

exchange, reliability/capacity value, grid effects, water/environment constraints and other system services. A positive window exists when the ceiling is at or above the investor floor.

21.2 Affordability proxy and evidence limits

As a first screening test, NEPRA's FY2024-25 average power-purchase components - approximately PKR 14.3/kWh capacity purchase price plus PKR 9.0/kWh energy purchase price - provide a system purchase-cost proxy of PKR 23.3/kWh. Selected published US-cent/kWh project or benchmark values are converted at the single 11 September 2026 SBP M2M exchange-rate snapshot solely to show their approximate position relative to that proxy. This is not a tariff determination, a present-value normalization or an investment ranking.

Table 21.2. Affordability screening of selected project and benchmark energy prices against the FY2024-25 power-purchase-cost proxy.

Case	Evidence price	Approx. PKR/kWh at dated SBP screening FX	Position vs 23.3 PKR/kWh proxy
Safe Solar tariff-petition case	5.48 USc/kWh	15.20	Below proxy by ~8.10
Hydro China Dawood wind	13.5244 USc/kWh	37.51	Above proxy by ~14.21
Karot hydropower	7.6152 USc/kWh	21.12	Below proxy by ~2.18
Engro Thar coal	8.5015 USc/kWh	23.58	Approximately at proxy
PTPL / Trimmu RLNG CCGT	6.5374 USc/kWh	18.13	Below proxy by ~5.17
Global geothermal 2024 LCOE	6.00 USc/kWh	16.64	Below proxy by ~6.66
Balochistan hybrid modeled PPA midpoint	6.56 USc/kWh	18.19	Below proxy by ~5.11

Sources: NEPRA FY2024-25 performance report; SBP 11-Sep-2026 FX snapshot; project and benchmark sources recorded in the companion evidence database. Evidence classes and vintages differ, so this is only a screening comparison.

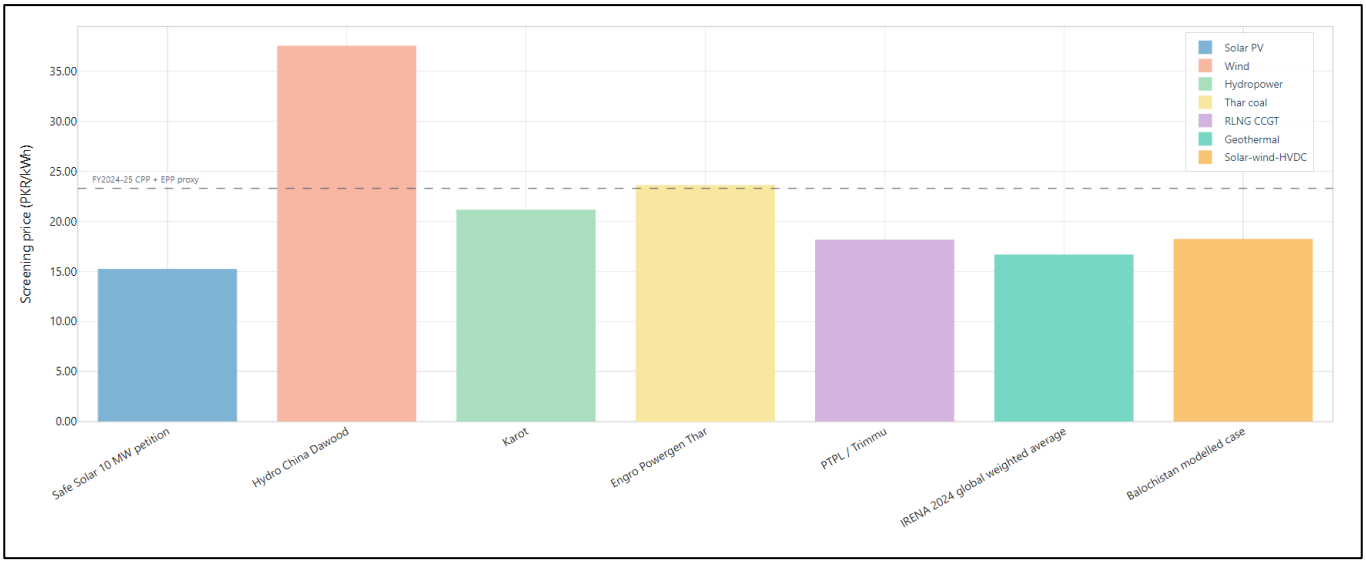


Figure 21.1. Screening price position versus FY2024-25 average power-purchase cost proxy.

Source: Integrated synthesis from NEPRA, SBP, PPIB/NEPRA project records, IRENA and World Bank evidence. Not a final bankability ranking.

21.3 What a final Bankability Window requires

A final project window requires current CAPEX and construction schedule, fixed and variable O&M, net generation and curtailment, tariff structure and indexation, debt/equity, interest and tenor, tax, FX/inflation, fuel/feedstock where applicable, water and environmental compliance, interconnection, replacement/decommissioning and downside

probabilities. The consumer ceiling additionally requires a chronological system alternative: what generation, fuel, transmission, storage or reliability cost is actually avoided if the study is built?

The Brill-Viz Economics template is suited to this structure because it can calculate project DCF, NPV, IRR/MIRR, cash-coverage indicators where configured, breakeven tariff, LCOE/LCOS, downside/base/upside cases, tornado sensitivity and Monte Carlo distributions. The energy-resource template supplies the physical resource and technical-performance inputs; the chronological system model supplies the avoided-cost ceiling.

PART VII - REGIONAL SOLUTIONS AND GLOBAL ANALOGUES

22. Regional Pakistan Energy Portfolios

22.1 Purpose and decision standard

Chapter 22 tests hypothesis E8 directly: whether materially different resource, water, grid, demand and deployment conditions imply different regional energy portfolios within Pakistan.

No screening score is treated as a least-cost optimization result. The regional matrix is a transparent prioritization aid whose categorical constraints remain visible.

22.2 Regional evidence architecture

The regional database combines four evidence streams. First, PPIB's 2022 hydropower inventory provides identified hydro potential and installed capacity by region. Second, the World Bank VRE Locational Study provides resource/grid evidence and a modelled 2030 distribution of solar-wind additions for the four provinces. Third, World Bank water diagnostics provide comparable provincial water-resource and withdrawal baselines for KP, Punjab, Sindh and Balochistan. Fourth, NEPRA's FY2024-25 distribution-performance report provides T&D loss, recovery and reliability metrics that can be used cautiously as regional network proxies. (PPIB, 2022; World Bank/ESMAP, 2021; World Bank, 2019; NEPRA, 2026)

*Table 22.1. Regional evidence baseline. *World Bank 2021 locational-study model result, not a forecast or current pipeline. Water figures are structural World Bank baseline estimates. Grid values use DISCO proxies and do not map perfectly to provincial boundaries. (PPIB, 2022; World Bank/ESMAP, 2021; World Bank, 2019; NEPRA, 2026)*

Region	Hydro potential / installed (MW)	WB 2030 VRE addition*	Water resource / withdrawal (bcm)	T&D loss / recovery proxy (%)	Regional screening direction
Punjab	7,316 / 2,524	3,290	97 / 118 (1.21x)	~11.15 / 101.3	Solar near load; nuclear firm; agro-bioenergy; flexible RLNG
Sindh	208 / 0	10,035	65 / 55 (0.85x)	~27.27 / 79.85	Wind-solar + grid/storage; K2/K3; existing Thar managed conditionally
Balochistan	5 / 0	10,196	14 / 4 (0.29x)	38.38 / 38.70	Solar-wind + storage; staged transmission; geothermal pilot
KP	27,013 / 5,789	280	24 / 7 (0.29x)	37.15 / 91.50	Hydro anchor; VRE complement; storage; network improvement

Region	Hydro potential / installed (MW)	WB 2030 VRE addition*	Water resource / withdrawal (bcm)	T&D loss / recovery proxy (%)	Regional screening direction
Gilgit-Baltistan	21,162 / 169	n/a	n/a	n/a	Local hydro + solar-storage; selective EHV; geothermal direct heat
AJK	8,296 / 2,370	n/a	n/a	n/a	Hydro anchor; solar-storage resilience; PSH/geothermal screening

The regional hydropower-potential versus installed-capacity comparison is shown in Figure 9.1 (Chapter 9) and is not repeated here.

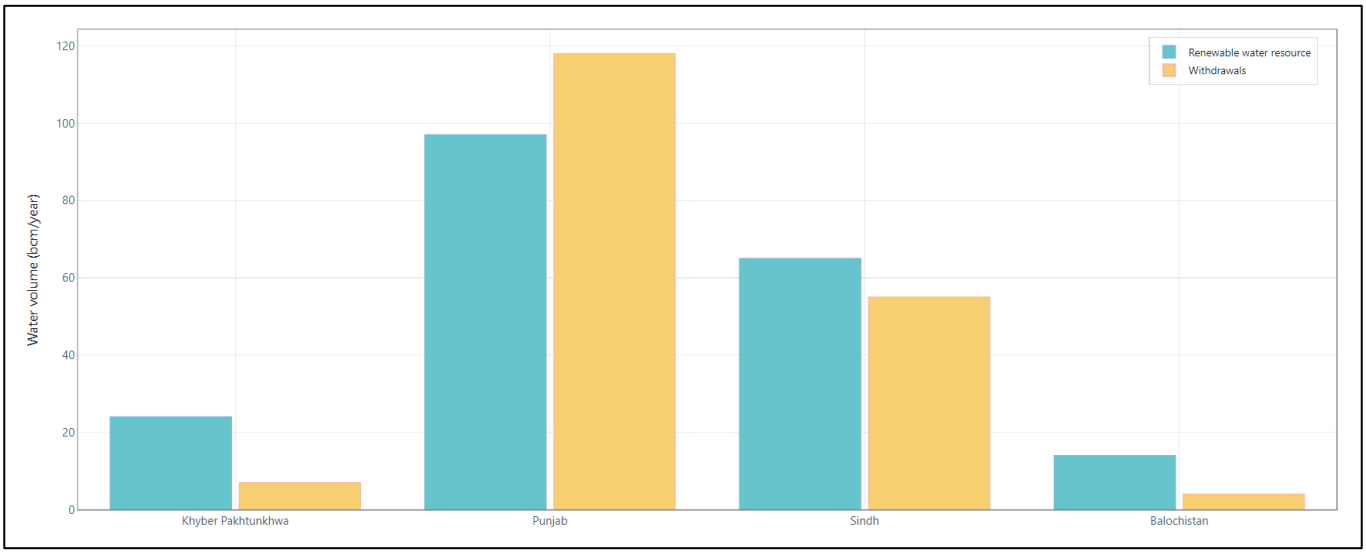


Figure 22.1. Provincial renewable water resource and withdrawals: structural baseline.

Source: World Bank, Pakistan: Getting More from Water (World Bank, 2019). The report warns that water security cannot be inferred from per-capita availability or relative-use ratios alone.

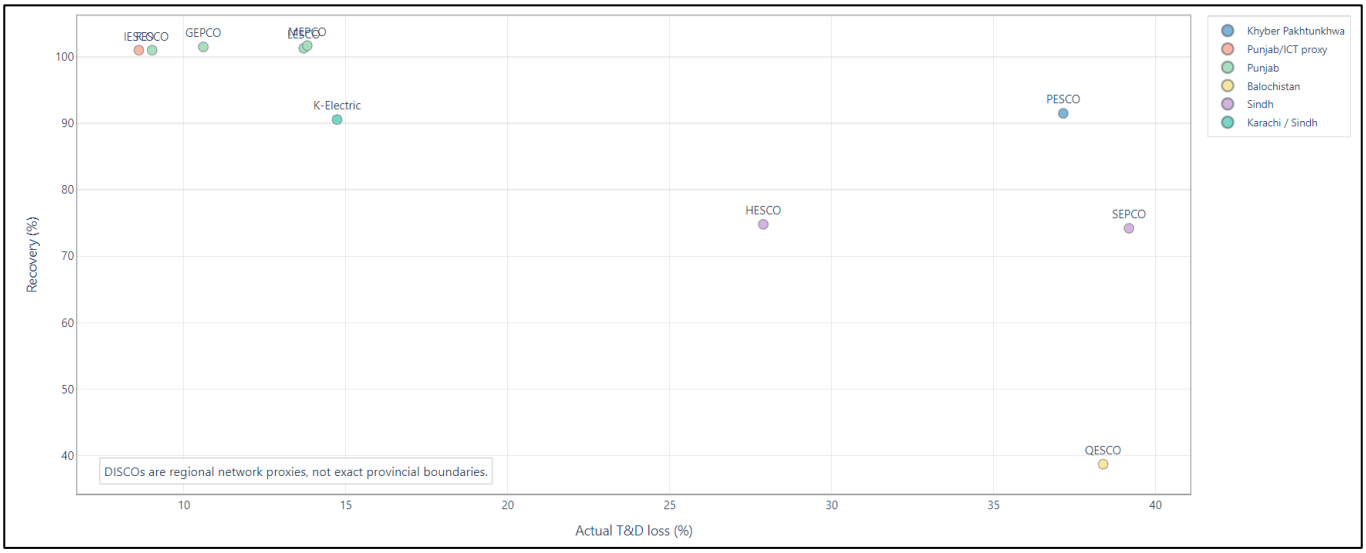


Figure 22.2. Distribution-network performance proxies, FY2024-25.

Source: NEPRA, Performance Evaluation Report of Distribution Companies FY2024-25 (NEPRA, 2026). DISCOs are network proxies, not exact provincial boundaries.

22.3 Punjab: load-centred solar, firm nuclear and flexible existing thermal capacity

The World Bank locational study identifies Punjab as having very good solar resources, a comparatively well-developed grid and many load centres, allowing generation to be consumed near its source. It also highlights a land-use constraint in central and upper Punjab and points to extensive suitable barren land in southern Punjab; wind potential is described as minimal. In the study's modelled 2030 VRE allocation, Punjab receives 3,290 MWp of additions (World Bank/ESMAP, 2021).

Punjab therefore screens as a solar-and-efficiency-led demand region rather than a wind-export region. PPIB's commissioned project register also shows a large existing gas/RLNG fleet in the province, approximately 6.0 GW in the projects captured by the register, along with about 530 MW of PPIB-facilitated utility solar and roughly 265 MW of bagasse capacity. The Chashma nuclear site adds an established firm low-carbon anchor. (PAEC, 2024; PPIB, 2026)

The water evidence changes the interpretation. The World Bank baseline reports renewable water resources of about 97 bcm and withdrawals of about 118 bcm for Punjab, with a relative-use ratio of 1.21, reflecting groundwater depletion in the underlying methodology. New water-intensive thermal capacity should therefore face a higher screening threshold than solar, efficiency, agro-bioenergy or grid upgrades. (World Bank, 2019)

Punjab screening direction: core actions are distributed and industrial solar, southern-Punjab utility solar where land and grid conditions are suitable, energy efficiency and grid modernization. Nuclear remains a firm-power option subject to project finance and cooling-water evidence. Existing RLNG capacity should be valued primarily for flexibility and firming against avoided import-fuel cost, rather than assumed to expand as import-intensive baseload. Bagasse/biogas is a complementary agro-industrial pathway. Geothermal in the Salt Range/Mianwali area remains a research/direct-use theme.

22.4 Sindh: wind-solar system with firm coastal generation and a constrained coal legacy

Sindh has the strongest mature wind deployment in Pakistan. PPIB's commissioned register lists about 1,845 MW of wind, concentrated mainly in Jhimpir and Gharo, while the World Bank locational study concludes that the corridors retain substantial further potential and that solar resources are also excellent across large barren areas. The same study's 2030 model allocates about 10,035 MW of VRE additions to Sindh. (World Bank/ESMAP, 2021; PPIB, 2026)

The system constraint is increasingly grid-related rather than resource-related. Chapter 11 documents the 2026 BEST-PAK case in which 640 MW of curtailed southern wind is explicitly targeted for recovery through grid-stability investment. NEPRA distribution evidence also shows large differences inside Sindh: HESCO and SEPCO reported high losses and weak recovery, while K-Electric performs under a separate regime. (World Bank, 2026; NEPRA, 2026)

Sindh simultaneously hosts 2.2 GW of operating K-2/K-3 nuclear capacity and 3.3 GW of PPIB-listed Thar-coal generation. This creates a distinctive firm-plus-variable portfolio opportunity, but also a difficult water and environmental trade-off. World Bank water evidence describes Sindh as among Pakistan's least water-secure provinces despite relatively high per-capita availability, partly because saline groundwater limits recovery/reuse opportunities. (PAEC, 2024; World Bank, 2019; PPIB, 2026)

Sindh screening direction: wind-solar hybridization, storage, transmission and distributed/industrial solar are core growth pathways. K-2/K-3 remain a firm low-carbon anchor. Existing Thar coal has real indigenous-fuel security value, but further expansion should be conditional on a full comparison of water, emissions, fuel cost, financing and long-run system competitiveness rather than resource abundance alone. Manghopir/Dadu geothermal remains a direct-use/resource-validation pilot theme.

22.5 Balochistan: exceptional VRE resource constrained by grid and water

The World Bank locational study gives Balochistan the clearest resource-versus-infrastructure contrast. It identifies excellent solar, the highest wind-resource potential among the provinces, large unused land areas and especially strong western resources near Chaghi. At the same time, it identifies lack of grid infrastructure as the main constraint. Its long-term concept includes an almost 1,000-km Chaghi-Muzaffargarh HVDC connection that could open roughly 8 GW of capacity; this remains a planning concept, not an operating asset (World Bank/ESMAP, 2021).

Water provides a second binding constraint. Current World Bank project evidence describes Balochistan as facing acute water scarcity, low storage, high variability and groundwater depletion. Consequently, the regional portfolio should prefer water-light power pathways and should not allow a low headline generation cost to hide freshwater competition (World Bank, 2025).

NEPRA's QESCO proxy reinforces the infrastructure problem: FY2024-25 reported T&D losses of 38.38% and recovery of 38.70%. These are not resource metrics, but they materially affect how new generation should be staged (NEPRA, 2026).

Balochistan screening direction: first develop local solar-wind hybrids, storage and load-centred projects for towns, industry and mineral-processing demand where they reduce local supply cost. Large export-oriented VRE should follow only when transmission and offtake are committed on a delivered-cost basis. Chagai/Koh-e-Sultan geothermal merits a staged exploration and direct-use pilot programme. New water-intensive imported-fuel generation should face a particularly high screening threshold.

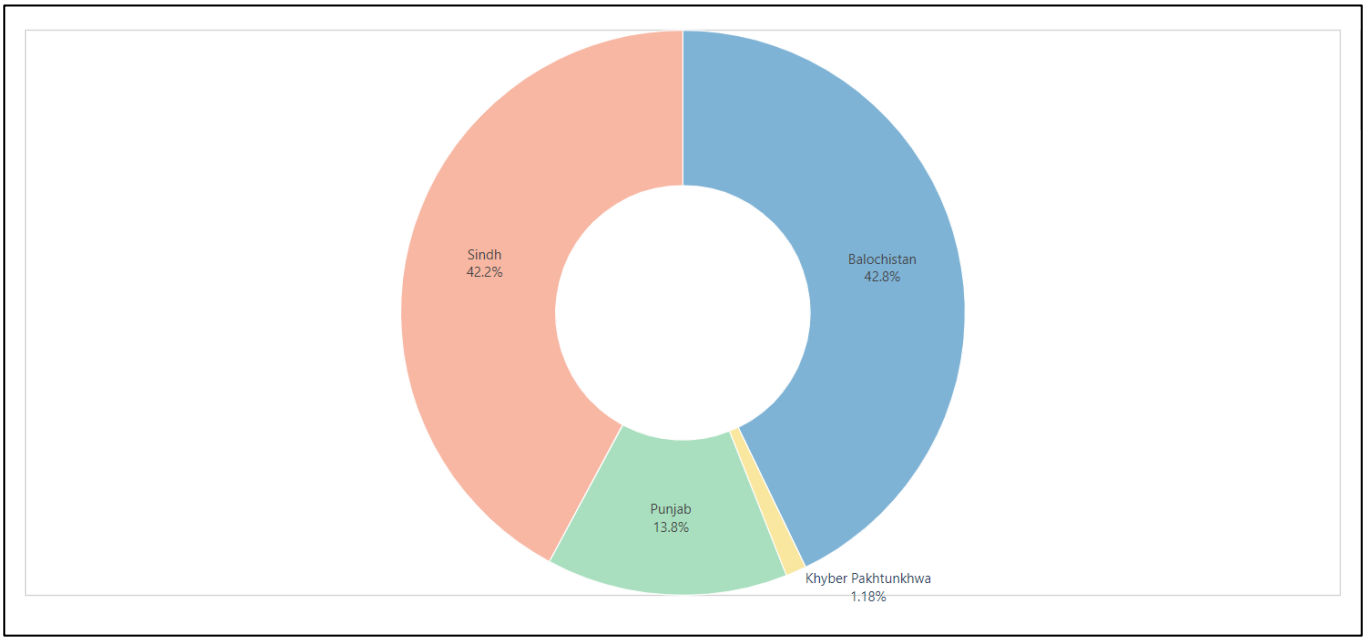


Figure 22.3. World Bank locational-study VRE additions by province for its 2030 scenario.

Source: World Bank / ESMAP, Variable Renewable Energy Locational Study (World Bank/ESMAP, 2021). These are model results from the study, not forecasts or current project commitments.

22.6 Khyber Pakhtunkhwa: hydropower anchor with grid and flexibility investment

PPIB's hydropower inventory identifies approximately 27.0 GW of hydro potential in KP, the largest provincial total in the inventory, with about 5.8 GW installed at the inventory date. The World Bank VRE study reaches the same directional conclusion from a different evidence stream: KP has less solar and wind resource than the other provinces and its natural focus should be hydropower, supplemented by VRE where good sites can be identified (PPIB, 2022; World Bank/ESMAP, 2021).

The opportunity is not equivalent to "build all hydro." Seasonal hydrology, environmental/community impacts, civil works, construction risk and evacuation must be included project by project. The distribution network is also a material constraint: PESCO reported 37.15% T&D losses and a SAIFI of 176.62 interruptions per customer in FY2024-25 (NEPRA, 2026).

Khyber Pakhtunkhwa screening direction: hydropower rehabilitation and carefully prioritized new hydro form the core. Solar can complement daytime and seasonal demand, especially in distributed/public-service applications; ADB's clean-energy programme provides a practical precedent for micro-hydro in rural/off-grid KP and decentralized solar in public facilities. Pumped-storage and battery sites should be screened around hydro/grid nodes, and Garam Chashma/Chitral geothermal should be tested initially for direct heat and small pilots (Kanwal et al., 2020; NEPRA, 2023; ADB, 2016).

22.7 Gilgit-Baltistan: local reliability first, then selective hydro export

Gilgit-Baltistan is an extreme example of why resource potential and system readiness must be separated. PPIB's 2022 inventory identifies about 21.2 GW of hydro potential but only about 169 MW installed. The same source explicitly notes limited local demand and absence of extra-high-voltage transmission as reasons much of the potential has not been developed (PPIB, 2022).

For Gilgit-Baltistan, the analysis does not rank gigawatt-scale hydro automatically above smaller local systems. The near-term regional portfolio should prioritize micro/small hydro, solar-storage microgrids and reliability for isolated valleys, then advance selected larger hydro only where an EHV evacuation and credible offtake plan exist. Documented hot-spring areas around Hunza, Murtazabad, Darkut and the Gilgit region justify geothermal direct-heat/resource studies, particularly where heating, tourism or agro-processing demand can use lower-temperature resources (Kanwal et al., 2020; PPIB, 2022).

22.8 Azad Jammu and Kashmir: hydro-dominant system with local resilience opportunities

AJK has approximately 8.3 GW of identified hydro potential and about 2.37 GW installed in the PPIB 2022 inventory. Its maturity is reinforced by operating projects including New Bong Escape and Gulpur, while the wider Jhelum/Neelum system connects regional resources to the national power system (PPIB, 2026).

Azad Jammu and Kashmir screening direction: hydropower remains the anchor, but local solar-storage can improve distribution resilience and diversify supply. Pumped-storage screening is justified by the hydro/reservoir setting, but no bankable public PSH site dataset has yet been acquired, so no MW/MWh claim is made. Tatta Pani provides a geothermal direct-use screening case rather than a proven power resource (Kanwal et al., 2020; NEPRA, 2023; NREL, 2024).

22.9 Regional priority matrix and what the scores mean

The companion evidence database assigns each region-technology pair five transparent screening dimensions on a 0-4 scale: resource evidence, deployment maturity, grid/system fit, water/environment fit and energy-security value. The simple average is used only to visualize evidence-weighted priorities. It is deliberately not a least-cost model, and it does not override categorical judgement where a critical constraint is non-linear. For example, Thar coal scores strongly on resource/maturity/security but remains conditional because water and environmental constraints are material; Balochistan VRE scores strongly on resource/security but remains grid-conditioned.

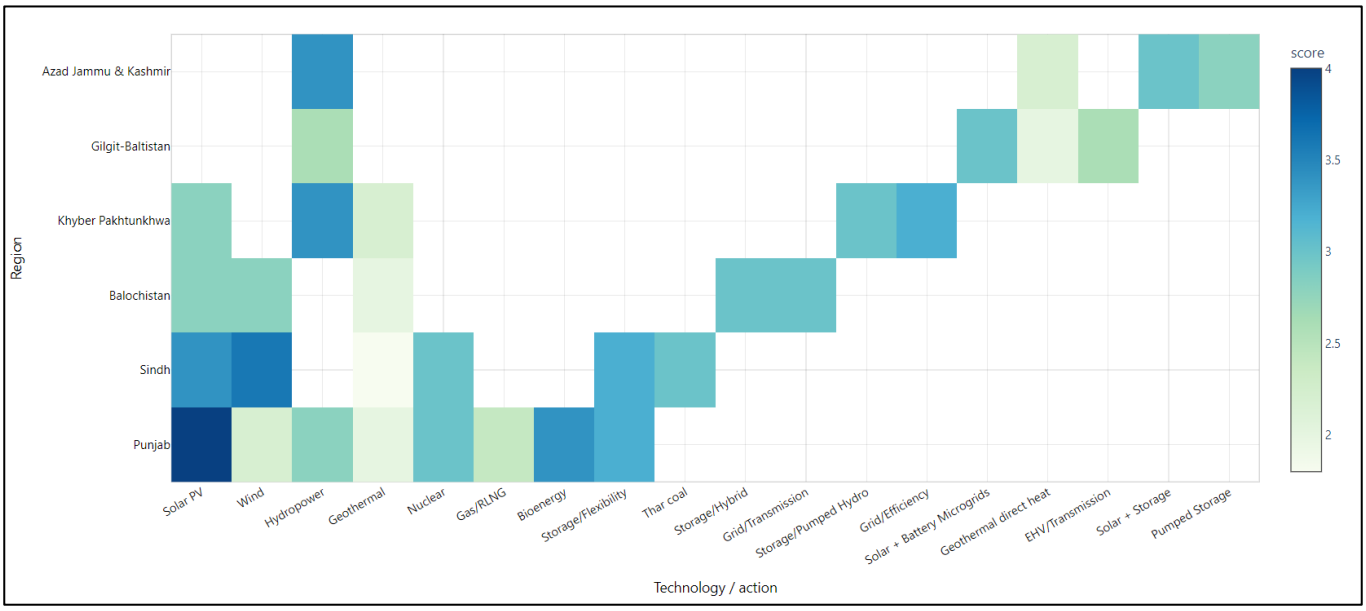


Figure 22.4. Regional technology/action screening matrix.

Source: Chapter 22 integrated-synthesis matrix. Scores are transparent internal screening values derived from published evidence; they are not published measurements or final optimized portfolio weights.

Table 22.2. Regional screening portfolio roles. These are integrated-synthesis categories, not capacity targets.

Region	Core	Complementary	Conditional / pilot
Punjab	Solar; efficiency/grid; nuclear firm power	Bioenergy; selective hydro; storage	RLNG as flexibility; geothermal pilot; wind low priority
Sindh	Wind-solar; grid/storage; nuclear firm power	Distributed/industrial solar; bioenergy	Thar expansion conditional; geothermal pilot
Balochistan	Solar-wind; storage/hybrid; grid build-out	Local gas where economic	Large export VRE conditional on transmission; geothermal pilot; avoid water-intensive expansion
KP	Hydropower; grid-loss reduction	Solar; storage/pumped hydro	Geothermal direct heat/pilot; wind selective
GB	Local hydro; solar-storage; transmission planning	Geothermal direct heat	Large hydro export only with EHV/offtake
AJK	Hydropower	Solar-storage; pumped-storage screening	Geothermal direct heat/pilot

22.10 Interregional architecture: Pakistan as one portfolio

The regional portfolios are not six independent power systems. Their value emerges through interregional complementarity. Northern hydro in KP, GB and AJK can provide indigenous energy and flexibility; Sindh offers mature wind plus solar and firm coastal nuclear; Balochistan offers very large but transmission-constrained solar-wind resource; Punjab combines large load centres, strong solar, nuclear, agro-bioenergy and an existing thermal fleet that can provide flexibility while fuel-import exposure is reduced. The national grid is therefore an energy resource in its own right, because it allows diverse regional generation profiles to substitute for fuel imports and reduce the storage capacity that would otherwise be required locally (World Bank/ESMAP, 2021; World Bank, 2026).

Chapter 24 carries this interregional logic into national screening pathways, but does not yet optimize transmission, storage and demand response chronologically. A province should not be forced to meet its own annual electricity demand if a lower-cost and more reliable national portfolio can exchange energy across regions. Equally, very remote generation should not be labelled low-cost until attributable transmission, losses, curtailment and reliability contribution are included.

22.11 Regional synthesis and residual uncertainties

This Chapter (22) provides enough evidence to partly support hypothesis E8: optimal portfolios differ materially among Pakistan's regions. The conclusion is robust at the level of portfolio direction, but not yet at the level of installed MW, annual GWh or investment share. The remaining gating inputs are regional hourly demand, actual generation/curtailment, project-specific water intensities, storage-site economics, distributed-solar production, current tariff components and location-specific transmission costs.

For that reason, Chapter 24 begins with the Chapter 22 regional portfolios as candidate resource sets and tests alternative national scenarios: reference extension, least-cost plus efficiency, water-constrained, import-minimization, high-renewable and balanced self-reliance. These are transparent screening pathways rather than final optimized capacity shares.

22.12 Integrated regional conclusions

- Pakistan’s energy-security problem is a portfolio and system-integration problem, not merely an installed-capacity problem.
- Installed capacity, generation, final consumption and import exposure must remain separate analytical quantities. Distributed/net-metered solar makes this distinction increasingly important.
- Water scarcity is sufficiently material to be a core optimization constraint rather than an environmental appendix.

- Global renewable cost benchmarks show that low-cost energy and high utilization are distinct dimensions; system value cannot be inferred from LCOE alone.
- Geothermal is potentially valuable because of firm power and direct heat, but Pakistan's current evidence is prospectivity-level and requires staged resource confirmation before bankable capacity claims.
- Indigenous coal has clear import-substitution value, but its optimal role cannot be established without full water, environmental, plant-efficiency, financing and system-cost comparison.
- Gas substitution must distinguish imported RLNG from indigenous gas and account for the alternative value of gas in industry, fertilizer and domestic use.
- The eventual roadmap should be regional, with different portfolios for different provinces/resource regions, and should integrate grid and demand-side solutions with new generation.
- Project economics will be evaluated through a common cash-flow framework, with an Investor-Consumer Bankability Window as a central decision test.
- The manuscript and the published data database should continue to evolve in parallel; recommendations will be upgraded only when the relevant evidence gap is closed.
- The project-economics evidence strengthens the geothermal conclusion: Pakistan has credible prospectivity, but sustainable flow and injection evidence is still the gating variable between prospect and bankable resource.
- The project evidence also establishes that cost and tariff comparisons must be normalized for project vintage, financing, currency and cost definition before any technology is ranked economically.
- Chapter 9 confirms hydropower as a large indigenous operating resource, but also shows that its economic and system value is inseparable from seasonal hydrology, storage function, water allocation and transmission.
- Official evidence confirms pumped-storage site assessment as a Pakistan planning activity, but the current public dataset used here is not yet sufficient for bankable capacity or cost claims.
- Pakistan has strong open solar and wind measurement/GIS evidence; processing the high-frequency QC datasets remains a priority for later hourly/monthly complementarity and dispatch analysis rather than relying only on atlas averages.
- The 2026 BEST-PAK evidence makes grid congestion quantitatively material: 640 MW of curtailed wind is explicitly targeted for recovery through transmission-stability investment.
- Large remote Balochistan solar-wind opportunities must be evaluated with dedicated transmission and hybridization, not with busbar generation cost alone.
- Chapters 18-21 demonstrate that reported project CAPEX and historical levelized tariff are not interchangeable measures of economic merit; project vintage, financing, fuel and indexation must be normalized before ranking.
- Pakistan H-class RLNG plants show relatively low reported capital intensity and high design availability, but their system economics remain strongly exposed to imported fuel, foreign exchange and low dispatch.
- NEPRA FY2024-25 evidence makes capacity cost a first-order economic variable: 61% of reported power purchase cost was capacity purchase price, while thermal-fleet utilization was 42.5%.
- PAEC unit-level statistics provide strong operating-performance evidence for nuclear power, but the C-5 PC-I cost cannot be converted into a bankable tariff or IRR without EPC-stage tariff, financing, O&M, fuel and evacuation inputs.
- Battery storage and large hybrid projects require service-stack and delivered-system economics rather than a conventional stand-alone generator LCOE comparison.
- The Brill-Viz economics export table is structured for direct population of common economic cases, while unsupported inputs remain blank and visible.
- Chapter 22 partly supports hypothesis E8: regional resource, water, grid and deployment evidence is sufficiently different that one uniform Pakistan technology ranking is not defensible.
- Punjab screens toward solar near load, efficiency/grid, firm nuclear, agro-bioenergy and flexible use of the existing RLNG fleet rather than wind-led development.
- Sindh screens toward wind-solar hybridization, grid/storage and firm coastal nuclear, while additional Thar-coal expansion remains conditional on water, emissions and full delivered-system economics.
- Balochistan has exceptional solar-wind resource but acute water and grid constraints; local hybrid systems and staged transmission are more defensible than assuming immediate gigawatt exports.

- KP, GB and AJK are hydro-dominant but differ in grid maturity; GB in particular demonstrates that enormous technical hydro potential is not equivalent to developable capacity without EHV and offtake.
- Regional distribution losses, recovery and reliability are economically material portfolio inputs: grid investment can compete with new generation as a source of usable energy and reliability.

23. Global Comparator Cases

23.1 Comparator rule: transfer functions, not national percentages

Chapter 23 completes the first functional comparator set. No country is treated as a model that Pakistan should copy in full. Instead, each comparator is selected for a demonstrated system function - geothermal development, VRE integration, hydro flexibility, dry-year management, exploration finance, district heating or institutional capability. Transferability is scored separately from the comparator's headline energy share.

Table 23.1. Global comparator functions, published indicators and transferable lessons for Pakistan's energy system.

Comparator	Evidence-based function	Key published indicator	Primary Pakistan lesson
Kenya	Geothermal-led renewable diversification	Nearly 90% renewable generation in 2023; geothermal 47%	Public resource development/de-risking plus diversified renewable system.
Denmark	High-VRE grid and sector coupling	Wind 54% of electricity in 2022; wind+bioenergy+solar 81%	Markets, interconnection, flexibility and heat-sector integration.
Norway	Hydro flexibility and electrification	Hydropower supplies more than 90% of electricity	Reservoir flexibility, transmission and electrification value.
New Zealand	Hydro-geothermal portfolio	More than 80% renewable electricity	Firm geothermal plus hydro; explicit dry-year planning.
Türkiye	Geothermal finance and private development	2024 geothermal LCOE ~USD0.033/kWh; CF ~91%	Risk sharing, drilling/development finance and private-sector scale-up.
Indonesia	High-risk geothermal development	2024 geothermal LCOE ~USD0.090/kWh	Exploration-risk mechanisms and public/concessional upstream support.
Iceland	Direct geothermal heat	Close to 100% renewable district heating	Direct heat and cascade use can create value below power-generation temperature thresholds.

23.2 Kenya - geothermal as part of a diversified renewable system

The IEA reports that Kenya generated nearly 90% of its electricity from renewable sources in 2023, with geothermal contributing about 47%, hydro 21%, wind 16% and solar 4%. The transferable lesson is not the 47% figure. It is the institutional sequence: resource development, risk reduction, grid expansion and private/public investment can allow geothermal to serve as a high-utilization anchor alongside hydro and variable renewables. Pakistan first needs comparable resource confirmation before the power-share lesson becomes relevant.

23.3 Denmark - variable renewables require system architecture

Denmark demonstrates the opposite resource structure. The IEA reports wind at about 54% of electricity in 2022 and wind, bioenergy and solar PV together at about 81%. Its relevance to Pakistan is the architecture supporting high variable-renewable penetration: interconnection, markets, flexible demand and strong sector coupling. Pakistan cannot simply copy the Danish mix because interconnection depth, market design and resource geography are different, but the operational lesson is directly relevant to Sindh/Balochistan wind-solar development.

23.4 Norway and New Zealand - hydro value is chronological

Norway demonstrates the system value of reservoir hydropower and interconnection, while New Zealand demonstrates a high-renewable hydro-geothermal system in which dry-year risk remains a central planning problem. Together they reinforce the conclusion from Chapters 15-17 that annual hydro potential is not enough: reservoir state, inflow chronology, seasonal demand and backup or flexible resources determine firm system value. This is highly relevant to Pakistan's Indus-basin hydro expansion.

23.5 Türkiye, Indonesia and Iceland - different geothermal lessons

Türkiye provides the strongest combined geothermal resource-finance analogue in the current comparison because it pairs high utilization with private investment and structured exploration-risk support. Indonesia is valuable precisely because geothermal development can remain expensive and risky even where the resource base is large. Iceland is less useful as a geological analogue but exceptionally useful for direct heat: its district-heating system demonstrates how geothermal value can be captured without converting every thermal resource into electricity.

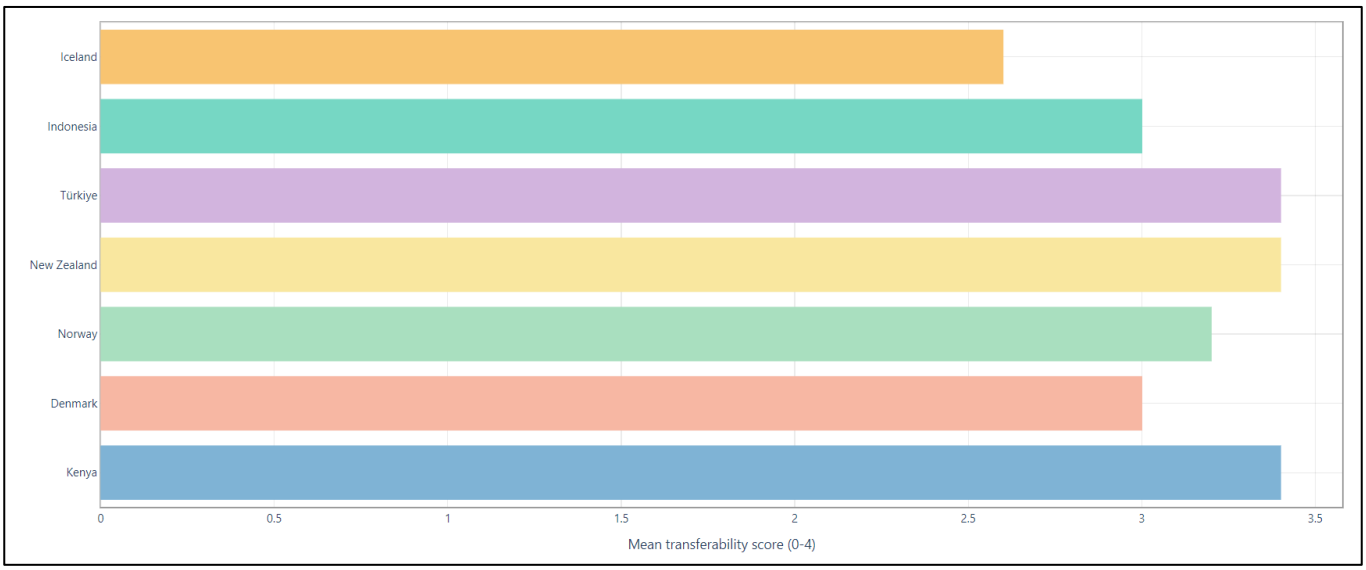


Figure 23.1. Functional global-comparator transferability screening.

Source: Integrated comparator scoring from IEA, IRENA and World Bank evidence. Scores are transparent screening judgements, not measured country performance.

23.6 Integrated comparator synthesis

The most defensible external model for Pakistan is therefore a portfolio of lessons rather than a single country: Kenya and Türkiye for geothermal development and de-risking; Indonesia for exploration-risk realism; Denmark for VRE system integration; Norway for hydro flexibility; New Zealand for dry-year and hydro-geothermal complementarity; and Iceland for direct geothermal heat. Future comparator work should extend this matrix to project-level finance, water intensity, transmission and market design wherever comparable public data are available.

23.7 From functional comparator to Pakistan prospective economics

Comparator countries are not used as direct cost substitutes. Their role is to identify functions and conditions that can be represented in the economics model: resource-confirmation sequence, private/public risk allocation, utilization, grid architecture, flexibility, reservoir management, direct-heat value or supply-chain scale. Where a cost benchmark is used, its currency year, scope and unit basis are retained before any Pakistan adjustment.

Table 23.2. Functional-comparator translation into prospective Pakistan economics.

Energy/system function	Comparator evidence used in the synthesis	Prospective Pakistan economics treatment
Geothermal exploration/development	Türkiye, Indonesia, Kenya; New Zealand reservoir management; Iceland direct heat	Separate exploration-risk EMV from development DCF; test success probability, wells, reinjection, risk sharing and direct-use value.
Wind/solar integration	Denmark; China scale/supply-chain context	Keep plant CAPEX separate from grid, curtailment, flexibility and transmission; Pakistan resource CF remains local.
Hydropower flexibility	Norway; New Zealand dry-year management; Himalayan regional context	Value annual energy, firm/flexible capacity, hydrology and reservoir state separately.
Bioenergy/sector coupling	Denmark system integration + Pakistan bagasse operating evidence	Use plant-specific feedstock, steam credit, seasonality and utilization rather than a uniform national CF.
Storage/grid services	International technology benchmark + Pakistan ADB service case	Model LCOS only after total CAPEX; value service stack, congestion, reserve and curtailment benefits separately.

23.8 Closing the comparative loop: from India, China and the United States to a functional learning framework

This synthesis originated partly from the comparative question raised by Khan, M. R., (2024): why have countries with different resource endowments developed such different energy mixes, and what can Pakistan learn from those differences? The original comparison focused primarily on Pakistan, India, China and the United States and particularly on the role of indigenous coal, the depletion of domestic gas and the economic consequences of imported fuels. The present synthesis retains that question but broadens both the evidence base and the meaning of comparison.

National energy shares are outcomes rather than transferable prescriptions. India's coal use, China's scale of generation and infrastructure development, or the United States' transition from coal toward abundant shale gas cannot be reproduced in Pakistan merely by adopting similar percentages. Each outcome reflects geology, resource availability, industrial structure, technology, capital markets, transmission infrastructure, environmental constraints and historical policy choices. The analytical value therefore lies not in asking what percentage of coal, gas, wind or hydro another country uses, but in identifying **which problem that country solved, how it solved it, what enabling conditions were required, and whether those conditions can reasonably be reproduced in Pakistan**.

India remains particularly relevant because it provides a large South Asian system operating under rapid demand growth, substantial indigenous coal use, major hydropower resources, rapidly expanding solar and wind capacity and many infrastructure and development constraints more comparable to Pakistan than those of smaller high-income systems. Its value in this synthesis is therefore regional and structural rather than as a target energy mix. China provides a different lesson: the importance of scale, domestic manufacturing, supply-chain development, large transmission systems and coordinated deployment of coal, hydro, nuclear, solar and wind. The United States demonstrates how technological change can alter an energy portfolio: advances in horizontal drilling and hydraulic fracturing substantially changed domestic gas supply and consequently the relative economics of coal and gas. These

cases illustrate that **energy security can change when indigenous resources become commercially deliverable through technology, infrastructure and scale**.

The additional comparator countries answer narrower questions that India, China and the United States do not answer as directly. Kenya provides experience in public geothermal resource development and de-risking; Türkiye in geothermal financing and private investment; Indonesia in high exploration risk; Denmark in variable-renewable integration and sector coupling; Norway in reservoir flexibility; New Zealand in hydro-geothermal complementarity and dry-year planning; and Iceland in direct geothermal heat. The resulting comparative framework therefore uses **a portfolio of international lessons rather than a single foreign model**. This is already the core principle of Chapter 23.

The outcome of the comparison is therefore not a recommended foreign energy mix for Pakistan. It is a set of tested questions that can be translated into Pakistan-specific economics: Can domestic resources be made commercially deliverable? What upstream risks require public or concessional sharing? What transmission must accompany remote renewable development? What flexibility is needed before high variable-renewable penetration becomes reliable? What is the value of reservoir storage, direct heat, demand response and avoided fuel imports? Which projects remain affordable after financing, water, grid and foreign-exchange exposure are included? These questions form the bridge between international experience and the Brill-Viz economic framework used in this study.

24. 2030-2050 Scenario Framework

24.1 Purpose: scenarios as decision tests, not forecasts

Chapter 24 moves from regional screening to quantified national pathways, but it does not treat a spreadsheet allocation as an optimized power-system plan. The near-term anchor is the Integrated System Plan (ISP) 2025-35 approved by NEPRA on 11 September 2026. Beyond 2035, the study uses six transparent screening pathways to test the consequences of different demand, water, import and renewable assumptions. Each post-2035 value is therefore tagged as an integrated-synthesis scenario input or derived output rather than as a published observation.

This distinction is necessary because the current official planning cycle ends in 2035 and because demand itself is uncertain. The revised IGCEP contains low, medium and high demand cases; older long-range official plans projected substantially higher 2040 demand, while an open-access 2023 LEAP study produced a lower-energy Green Recovery pathway. Chapter 24 preserves these differences instead of combining them into one apparently precise forecast.

24.2 Published planning anchors through 2035

The revised low-BAU IGCEP projects base electricity demand of about 157.3 TWh and peak demand of 30.94 GW in 2030, rising to 180.6 TWh and 35.52 GW in 2035. The medium and high cases reach approximately 199.0 and 219.0 TWh respectively by 2035. The approved/reference 2035 system contains 62.657 GW of installed capacity. Pakistan's NDC 3.0 cites about 38.472 GW of renewable capacity including hydropower and 43.202 GW of clean capacity including nuclear, or roughly 61% and 69% of the planned capacity mix.

The Pakistan Energy Outlook 2021-2030 is retained as an earlier official planning benchmark rather than as a competing current forecast. Its demand framework used an ARIMA approach with seasonal variation and exogenous variables, drawing on an Integrated Energy Planning database assembled from monthly 2006-2020 primary-stakeholder data and variables including economic activity, energy prices, population and urbanization. The report projected 2030 electricity generation/supply of about 230.18 TWh, with more than half from hydel and non-hydro renewables and about 31% from fossil generation. Its value here is methodological and historical: it shows what the 2021-22 planning system expected, while the present manuscript compares those expectations with later demand, distributed-solar, utilization and planning evidence rather than splicing the series together (Ministry of Planning, Development & Special Initiatives, 2022).

Table 24.1. Current published demand and capacity anchors retained for the scenario framework.

Demand case	Year	Base demand (TWh)	Peak (GW)	Installed capacity (GW)	Evidence use
Low BAU	2030	157.3	30.94	53.90	Current revised IGCEP planning anchor
Low BAU	2035	180.6	35.52	62.66	Approved/reference framework
Medium	2030	165.1	32.48	-	Demand sensitivity
Medium	2035	199.0	39.13	66.46	Demand sensitivity
High	2030	173.2	34.07	-	Demand sensitivity
High	2035	219.0	43.07	70.72	Demand sensitivity

Source: revised IGCEP 2025-35 and NEPRA ISP determination. Scenario values are planning-model outputs, not observations.

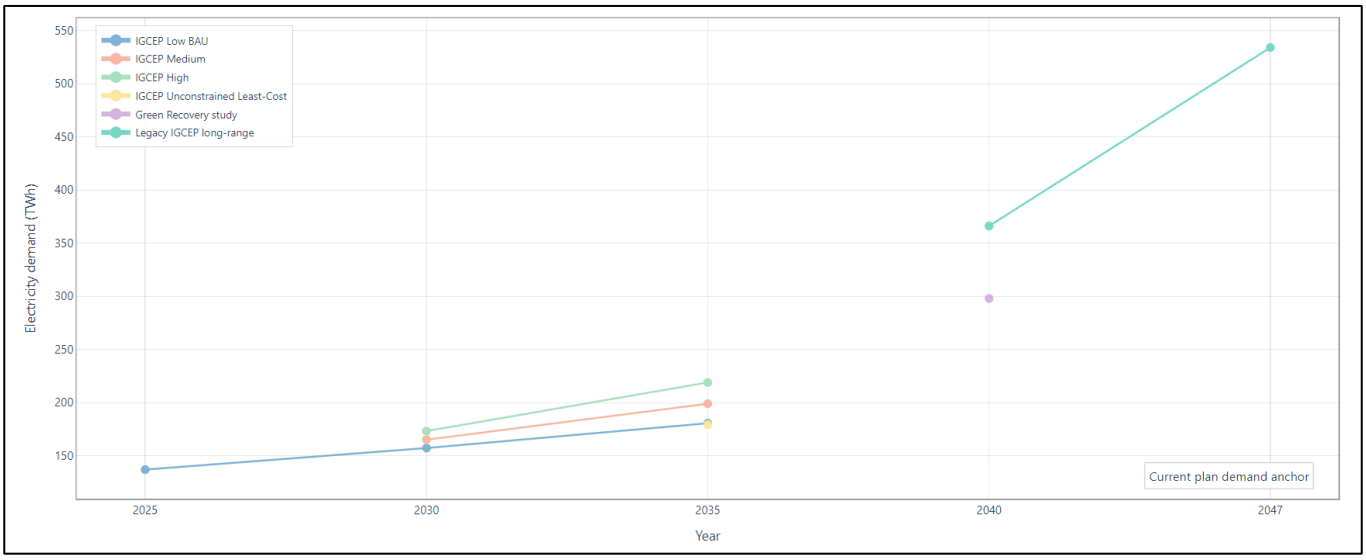


Figure 24.1. Published electricity-demand projection envelope retained as scenario context.

Source: revised IGCEP 2025-35 for 2025-2035; legacy IGCEP 2047 for historical long-range points. The legacy series is not a current official forecast.

24.3 The approved/reference 2035 supply structure

The reference 2035 capacity mix is already diversified. Hydropower is the largest category at about 21.4 GW, followed by solar PV at 11.5 GW, RLNG at 8.2 GW, wind at 5.1 GW and nuclear at 4.73 GW. Local coal is retained at 3.3 GW, imported coal at 4.68 GW, and RFO remains a small but non-zero legacy/imported-fuel class at about 0.819 GW in the reference table. Chapter 24 therefore begins from a system that is structurally different from Pakistan's recent thermal-dominated fleet. The RFO entry is treated as a planning-model result rather than a commitment to new liquid-fuel capacity.

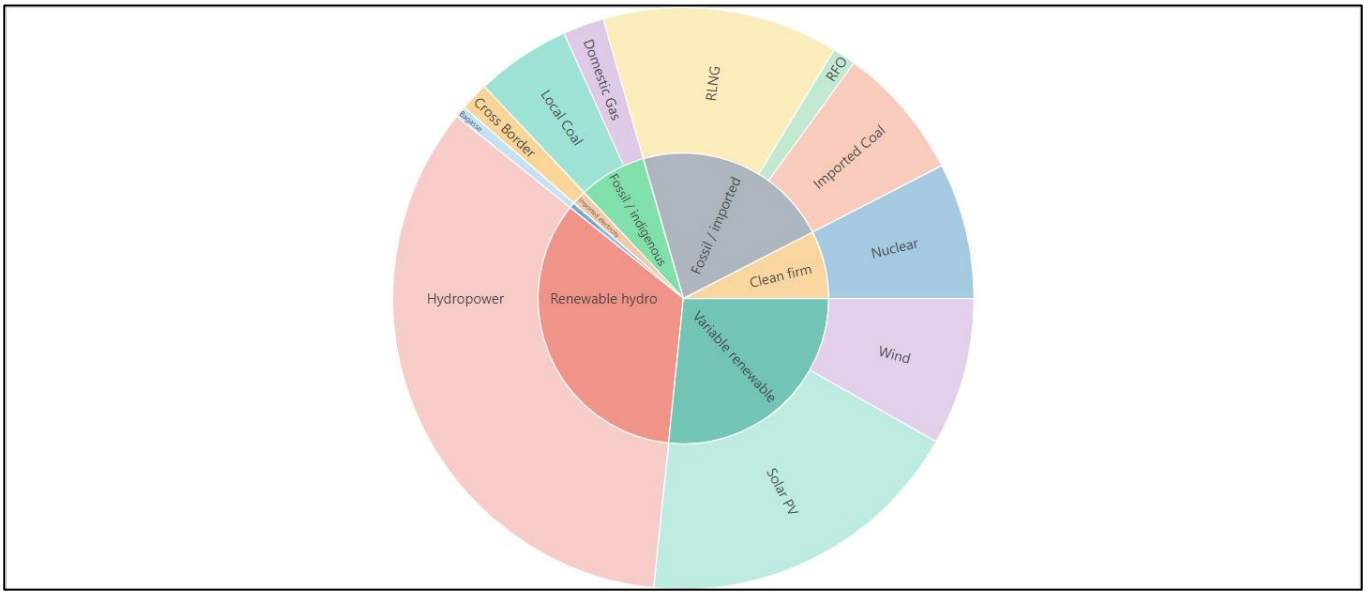


Figure 24.2. IGCEP 2035 reference installed-capacity mix.

Source: revised IGCEP 2025-35. Capacity is not generation and does not by itself measure system value or utilization.

A second important planning signal is what NEPRA did not approve. The Authority excluded the proposed BESS investment and a proposed 2028 K-Electric transmission-line item from the approved case pending fuller technical-economic justification. Chapter 24 therefore treats storage as a stress-test requirement, not as an automatically justified procurement quantity.

24.4 Post-2035 scenario design

All six pathways use the 2035 low-BAU demand level as a common starting point and then vary post-2035 demand growth, load factor, generation shares and flexibility intensity. The assumptions are deliberately visible in the workbook so that they can be replaced later by an hourly production-cost model. They test direction and burden: how much demand, firm capacity, variable renewable energy, imported-fossil exposure and flexibility would accompany each strategy.

Table 24.2. Post-2035 screening scenarios used in Chapter 24.

ID	Scenario	Post-2035 demand CAGR (%)	Primary test
REF	ISP Reference Extension	2.6	Continuity with current planning direction; gradual reduction in imported fuel.
LCE	Least-Cost + Efficiency	1.8	Lower demand growth and better load factor; strong VRE/hydro plus firm support.
WAT	Water-Constrained	2.0	Penalizes freshwater-intensive expansion; stronger solar/wind and low-water options.
IMP	Import-Minimization	2.3	Tests very low direct imported-fossil generation while retaining reliability resources.
HRE	High-Renewable	2.6	Stress-tests much higher solar/wind shares and the resulting flexibility burden.
BAL	Balanced Self-Reliance	2.1	Integrated synthesis: efficiency, regional renewables, hydro/nuclear firming and declining imported fuel.

The scenarios do not contain a hidden claim that a particular 2050 mix is optimal. In particular, the Import-Minimization pathway removes direct imported-fossil generation by assumption, while the High-Renewable pathway deliberately imposes an aggressive VRE boundary condition. Their purpose is to reveal what additional grid, storage, firming, water and investment evidence would be required.

24.5 Screening results for 2040 and 2050

Table 24.3. Chapter 24 screening outputs. Values are derived from transparent scenario assumptions, not forecasts.

Scenario	2040 demand TWh	2050 demand TWh	Clean % 2040	Clean % 2050	VRE % 2040	VRE % 2050	Imported fossil % 2040	Imported fossil % 2050	Flex GW 2040	Flex GW 2050
REF	205.3	265.4	87.0	93.0	27	37	4.0	1.5	2.02	4.18
LCE	197.5	236.0	93.5	97.5	37	48	1.5	0.5	2.82	4.83
WAT	199.4	243.1	93.0	98.0	44	59	2.5	0.5	3.61	6.31
IMP	202.4	254.0	95.0	98.0	32	41	0.0	0.0	2.98	5.35
HRE	205.3	265.4	95.0	98.5	45	60	1.5	0.25	4.69	9.62
BAL	200.4	246.7	94.0	98.5	36	48	1.0	0.25	2.86	5.88

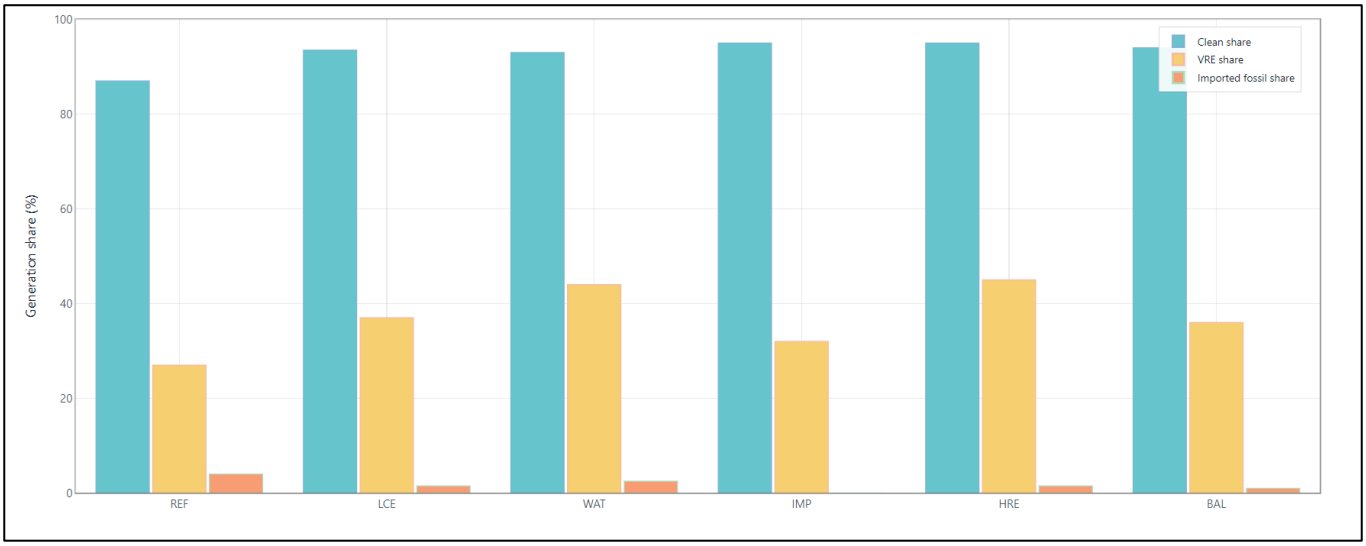


Figure 24.3. Scenario screening comparison for 2040.

Clean includes hydro, solar, wind, nuclear, bioenergy and geothermal in this screening definition. Imported-fossil share covers imported coal and RLNG direct generation.

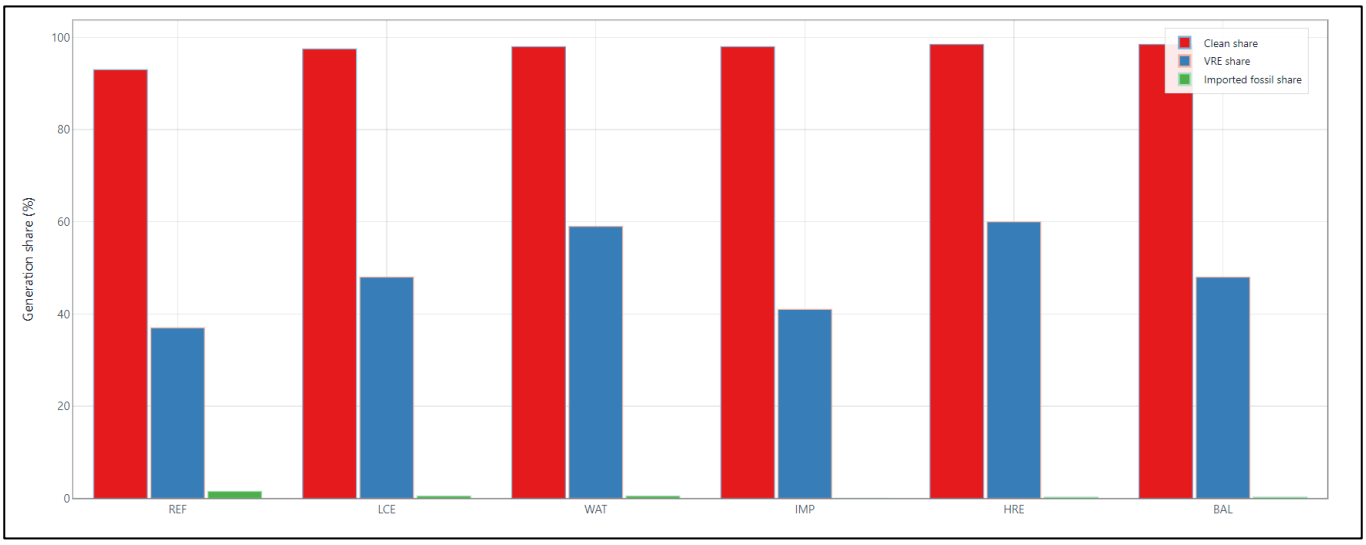


Figure 24.4. Scenario screening comparison for 2050.

These shares are stress-test assumptions/derived outcomes and must not be read as official 2050 policy targets.

24.6 Demand-side value and peak requirement

Demand management materially changes the amount of supply infrastructure that must be built. In the Reference Extension, electricity demand reaches about 265.4 TWh by 2050. The Least-Cost + Efficiency pathway reaches about 236.0 TWh, roughly 29.4 TWh lower, while the Balanced Self-Reliance pathway reaches about 246.7 TWh, about 18.8 TWh lower. The corresponding screening peak is about 52.2 GW in the Reference Extension versus 40.2 GW in the efficiency case and 42.0 GW in the balanced case. These differences arise from the assumed demand-growth and load-factor trajectories; they demonstrate the possible scale of demand-side value but do not yet constitute an efficiency investment appraisal.

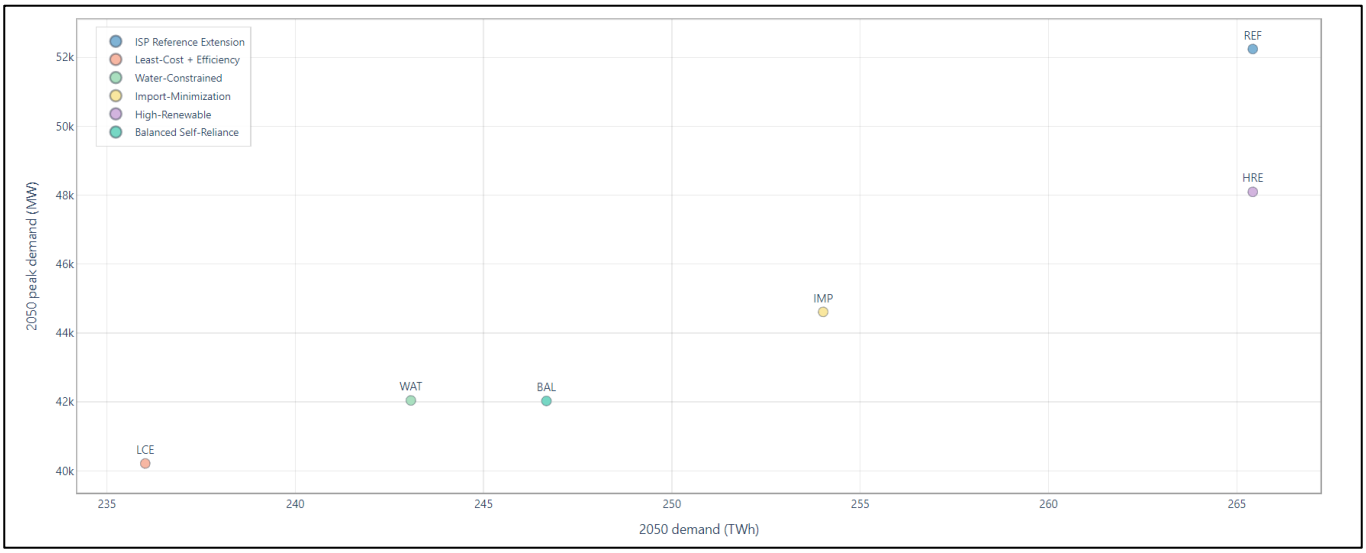


Figure 24.5. Demand and peak sensitivity across the Chapter 24 scenario pathways in 2050.

Peak values are derived from scenario demand and load-factor assumptions; hourly load modelling is still required.

24.7 Storage and flexibility: a stress test, not a procurement plan

Higher solar and wind shares increase the need for flexibility, but the relevant solution can be a portfolio of batteries, pumped storage, reservoir hydro, flexible thermal units, transmission, demand response and curtailment management. Chapter 24 therefore expresses a simple flexibility/storage power stress test rather than assigning all requirements to batteries. The 2050 screening requirement ranges from roughly 4.2 GW in the Reference Extension to 9.6 GW in the High-Renewable pathway, with the Balanced Self-Reliance case at about 5.9 GW. At the assumed four-hour duration this is a sizing diagnostic only; it is not an approved BESS target.

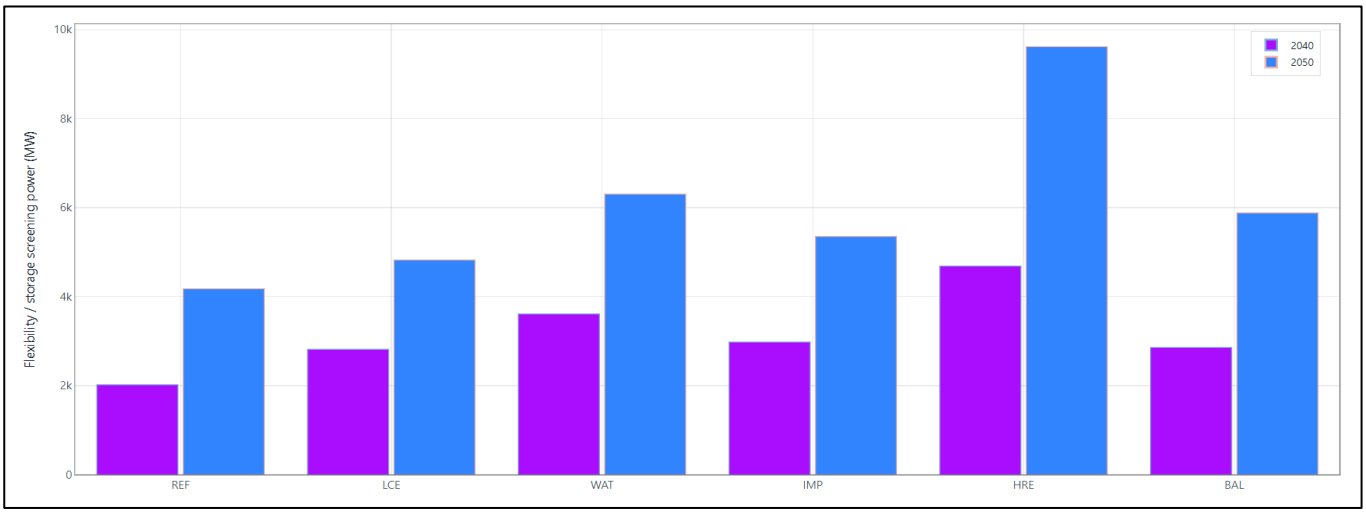


Figure 24.6. Flexibility and storage screening power in the Chapter 24 scenario pathways.

NEPRA excluded the proposed BESS investment from the approved ISP case pending fuller technical-economic justification; these values are therefore scenario stress tests only.

24.8 Indicative capacity conversion and the reserve-margin caveat

The workbook converts generation shares into energy-equivalent indicative capacity using explicit capacity-factor assumptions. This is useful for checking order of magnitude, but it is not a capacity-expansion solution because it omits unit retirements, forced outages, reserve margin, chronological hydrology, hourly solar/wind coincidence, transmission constraints and unit-commitment requirements. For that reason, the indicative 2040 totals can be below the 2035 reference nameplate capacity in some pathways even though demand is higher: the conversion represents energy-equivalent capacity, not dependable capacity adequacy.

The capital-envelope sheet is similarly partial. It applies sourced USD/kW proxies only where an appropriate benchmark is available and intentionally leaves nuclear, imported-coal and cross-border cost proxies blank. It should be read as a data-completeness and sensitivity instrument rather than as Pakistan's 2050 investment bill.

24.9 Interpretation of the six pathways

- Reference Extension tests continuity. It preserves the current planning direction and provides the baseline against which efficiency, water and import constraints can be measured.
- Least-Cost + Efficiency shows that demand-side performance can reduce both annual energy and peak requirements before additional generation is purchased. Its economic merit still requires a Pakistan efficiency cost curve.
- Water-Constrained shifts more strongly toward solar and wind and raises the flexibility requirement. It cannot be finalized until project/site water withdrawal and consumption are normalized.
- Import-Minimization demonstrates the boundary condition of eliminating direct imported-coal and RLNG generation in the scenario. Feasibility depends on dependable indigenous/clean firm capacity and transmission, not on the assumed fuel share alone.
- High-Renewable is the strongest grid/flexibility stress test. Its 2050 solar-plus-wind share reaches 60% in the screening mix and therefore carries the largest flexibility/storage diagnostic.
- Balanced Self-Reliance is the present integrated synthesis rather than a fixed target. It combines lower demand growth, regional solar/wind, hydro and nuclear firming, selective geothermal/bioenergy, storage/flexibility and a very small residual imported-fossil share by 2050.

24.10 Hypothesis evaluation under the scenario framework

Chapter 24 strengthens the portfolio hypothesis (E1), the water-constraint hypothesis (E3), the complementarity hypothesis (E5), the regional-differentiation hypothesis (E8) and the demand-side hypothesis (E10), but none is yet considered fully resolved. E7 is now partly supported qualitatively because the import-minimization pathway shows how portfolio choices can reduce direct imported-fuel generation; the avoided foreign-exchange value must still be monetized. E9, the Investor-Consumer Bankability Window, remains untested at national portfolio scale because full technology cash flows and delivered-system cost are still incomplete.

25. Integrated Roadmap and Decision Gates

25.1 From scenario screening to an adaptive roadmap

Chapter 24 does not establish one immutable 2050 technology quota. Instead, it supports an adaptive decision framework in which near-term actions, recurring plan updates and explicit evidence gates can be tested before capital-intensive commitments. This is consistent with rolling system planning and with uncertainty in future demand, distributed generation, financing cost and technology performance.

25.2 Phased roadmap

Table 25.1. Phased national roadmap derived from the Chapter 24 scenario framework.

Period	Strategic phase	Priority actions	Primary gate
2026-2030	No-regrets execution	Reconcile grid demand with rooftop/captive solar; execute justified committed hydro, nuclear and VRE; cut DISCO losses; relieve southern wind constraints; build the national geothermal evidence base.	Demand, grid and project delivery.
2031-2035	Complete the approved-plan cycle adaptively	Complete major hydro/C-5/renewable additions only as rolling ISP updates confirm need; expand transmission; use RLNG increasingly for flexibility; begin validated geothermal direct-use pilots.	Affordability, demand realism and project bankability.
2036-2040	Scale regional portfolios	Scale Punjab/Sindh solar, Sindh wind, northern hydro, Balochistan hybrid/local systems and location-specific storage/PSH where avoided system cost is demonstrated.	Hourly dispatch, water and transmission economics.
2041-2050	Deep self-reliance and electrification	Raise clean/indigenous contribution, deepen efficiency and electrification, retire imported-fuel generation where reliability permits, and expand firm clean resources only when bankable.	Future rolling-plan evidence; no fixed quota.

25.3 Decision gates before major commitments

Table 25.2. Evidence gates carried forward from Chapter 24.

Gate	Decision	Minimum evidence to pass
DG1 Demand	Generation beyond committed pipeline	Spatial demand, behind-the-meter generation and load evidence must demonstrate need.
DG2 Storage	Large BESS procurement	Locational reliability requirement, service stack, optimal duration, degradation/replacement and benefit-cost study.
DG3 Geothermal	Commercial power project	Measured temperature, sustainable flow/productivity, reinjection/injectivity, chemistry, drilling cost and risked economics.
DG4 Remote VRE	Large Balochistan export park	Committed offtake plus transmission, curtailment and delivered-cost economics.
DG5 Coal/Thermal	New capacity or life extension	Fuel, water, emissions, capacity-payment and alternative-system comparison.
DG6 Hydro/PSH	Major new storage project	Seasonal hydrology, environmental flow, resettlement, geotechnical and opportunity-cost evidence.
DG7 Nuclear	Additional new build beyond approved projects	Financing/EPC, water/cooling, evacuation and consumer-tariff analysis.

25.4 Regional architecture inside the national roadmap

Chapter 22 establishes that national self-reliance cannot be achieved by applying one technology ranking everywhere. Chapter 24 retains that regional logic inside the national scenarios: Punjab is primarily a load-centred solar, efficiency, firm-nuclear and flexible-thermal region; Sindh combines wind, solar and firm coastal generation; Balochistan is a high-quality VRE and geothermal-research province constrained by water and transmission; KP, GB and AJK are hydro-dominant but differ sharply in grid maturity and local demand. The national model must therefore optimize interregional transmission and complementarity rather than simply aggregate provincial resource potential.

25.5 Investor-consumer bankability must remain a project gate

A scenario can be physically attractive and still be financially unimplementable. The Investor-Consumer Bankability Window introduced earlier remains the bridge from system planning to investment. For each candidate project, Brill-Viz Economics can calculate the investor floor tariff under sourced CAPEX, OPEX, financing and risk assumptions, while the system analysis estimates the consumer/system ceiling from avoided fuel, capacity value, reliability, grid cost, import savings and environmental/water constraints. Where the investor floor exceeds the defensible system ceiling, the model identifies the gap and the extent to which redesign, risk reduction, different financing or deferral would be required to close it.

25.6 Integrated national decision framework

- Planning-anchor option: use the approved ISP 2025-35 as the near-term reference while re-testing demand as distributed solar, affordability and demand-side changes alter grid requirements.
- System-value option: evaluate transmission, distribution-loss reduction, metering/data quality and flexibility alongside generation as competing uses of capital.
- VRE decision test: compare solar and wind at strong resource/grid locations on delivered-system cost, including curtailment, transmission, firming and flexibility.
- Hydro decision test: separate technical potential from developable, environmentally acceptable and financeable sites, including seasonal hydrology and evacuation.
- Nuclear decision test: compare firm-energy value with financing, water/cooling, construction and evacuation requirements within the bankability window.
- Existing-thermal option: test the RLNG fleet as flexibility/capacity as well as energy supply, with dispatch determined by fuel/FX cost, utilization and reliability value.
- Thar-coal decision test: compare existing-asset/security value and any expansion case with alternatives on full delivered cost, water, environmental and financing constraints.
- Geothermal decision test: use staged resource confirmation, exploration-risk economics and direct-use/power cases before assigning capacity or investment value.
- Storage decision test: evaluate the required service, location, duration and avoided system cost before converting flexibility needs into a BESS or pumped-storage investment case.
- Demand-side option: compare efficiency, demand response and electrification measures with supply-side investments on avoided generation, fuel, peak and network cost.

25.7 Scenario synthesis

The evidence assembled through Chapters 15-25 supports testing portfolio pathways rather than a single-resource prescription. One screening pathway combines lower demand growth through efficiency, regionally differentiated renewable expansion, hydro and nuclear firm supply, stronger grids, location-specific storage/flexibility, lower imported-fossil utilization and staged development of under-characterized indigenous resources such as geothermal. The exact 2040 and 2050 shares remain unresolved because chronological system operation, water intensities, transmission expansion, future technology costs and bankable project cash flows are not yet fully modelled.

Accordingly, the Balanced Self-Reliance scenario is retained only as an integrated synthesis case for the next analytical stage. Its suitability remains to be tested by hourly production-cost modelling and by the Investor-Consumer Bankability Window rather than by narrative preference.

25.8 Integrated system synthesis

The integrated system evidence developed across Chapters 15-25 strengthens the central argument of this synthesis. First, chronological evidence confirms that Pakistan's problem cannot be solved by comparing installed megawatts: FY2023-24 demand ranged from about 7.0 GW to 30.15 GW while average load served was about 18.46 GW. Second, historical dispatch modelling shows that operational and contractual flexibility can have billion-dollar-scale system consequences. Third, global comparators show that successful systems rely on different combinations of firm resources, flexible grids, risk-sharing institutions and sector coupling rather than on one universal technology share. Fourth, the Investor-Consumer Bankability Window is defined as a two-sided decision test rather than a plant-LCOE comparison.

The most important unresolved issue is now data rather than conceptual structure. A final preferred 2040/2050 portfolio still requires an auditable current chronological model with demand, VRE, hydro, plant availability, fuel/FX, transmission and reserves. The companion evidence database is structured so those series can be inserted without changing the evidence architecture.

25.9 Prospective project economics as a decision screen

The prospective economics layer is intended to test conditions rather than pre-select technologies. For a candidate project, the analytical sequence is: identify the case basis; normalize the benchmark or project evidence; apply Pakistan/site adjustments; run full-life DCF only when the input gate is satisfied; run sensitivity and P10/P50/Mean/P90 uncertainty; calculate the investor floor; and compare it with the defensible consumer/system ceiling.

For policy analysis, the most useful output is therefore not a single assumed LCOE. It is a set of decision conditions showing which variables - resource quality, project scale, CAPEX, financing, FX, fuel, utilization, grid connection, water, risk allocation or system value - determine whether the project can enter the bankability window.

PART VIII - CHRONOLOGICAL SYSTEM ANALYSIS AND BANKABILITY APPLICATIONS

26. Chronological System Evidence

26.1 Chronological evidence and data completeness

Chapters 15-17 identify current chronology as the principal remaining evidence gate. Chapters 26-28 advance that work by adding FY2024-25 monthly peaks, monthly average and minimum demand, selected monthly-average hourly profiles, seasonal evening ramps, demand-response cases and hourly marginal-cost evidence. The principal source is a publicly accessible analytical dashboard that explicitly states that it uses the official ISMO FY2024-25 8,760-hour system-demand profile. Because this study has not yet independently downloaded and validated the original ISMO raw file, the values are classified as secondary-derived evidence. This is stronger than an assumed load shape, but weaker than an independently audited primary hourly dataset.

26.2 The FY2024-25 load envelope is strongly seasonal

Table 26.1. FY2024-25 monthly demand envelope, excluding K-Electric.

Month	True peak MW	Average MW	Minimum MW	Peak hour
Jul-24	23,066	19,392	12,628	H23
Aug-24	22,991	17,164	11,618	H00
Sep-24	20,559	16,858	12,724	H23
Oct-24	18,399	13,444	10,437	H20

Month	True peak MW	Average MW	Minimum MW	Peak hour
Nov-24	13,639	10,742	7,848	H17
Dec-24	13,127	10,127	7,251	H17
Jan-25	13,466	10,523	7,867	H18
Feb-25	12,736	9,947	6,484	H19
Mar-25	15,661	10,938	5,832	H18
Apr-25	19,346	14,205	6,976	H18
May-25	22,003	16,665	8,534	H23
Jun-25	23,817	18,528	12,190	H00

Source: Khan (2026), Pakistan Cooling Demand & System Peak Integration, derived from stated ISMO 8,760-hour system demand data. Secondary-derived evidence in this synthesis.

The largest monthly true peak in the acquired series is 23,817 MW in June 2025, while the lowest monthly true peak is 12,736 MW in February 2025. The scale of this seasonal difference is analytically important: adequacy, reserve, storage and transmission cannot be tested using one annual-average load. May has the largest peak-to-minimum spread in the Chapter 26 monthly table, while summer peaks occur very late in the day or around midnight and winter peaks move into the early evening.

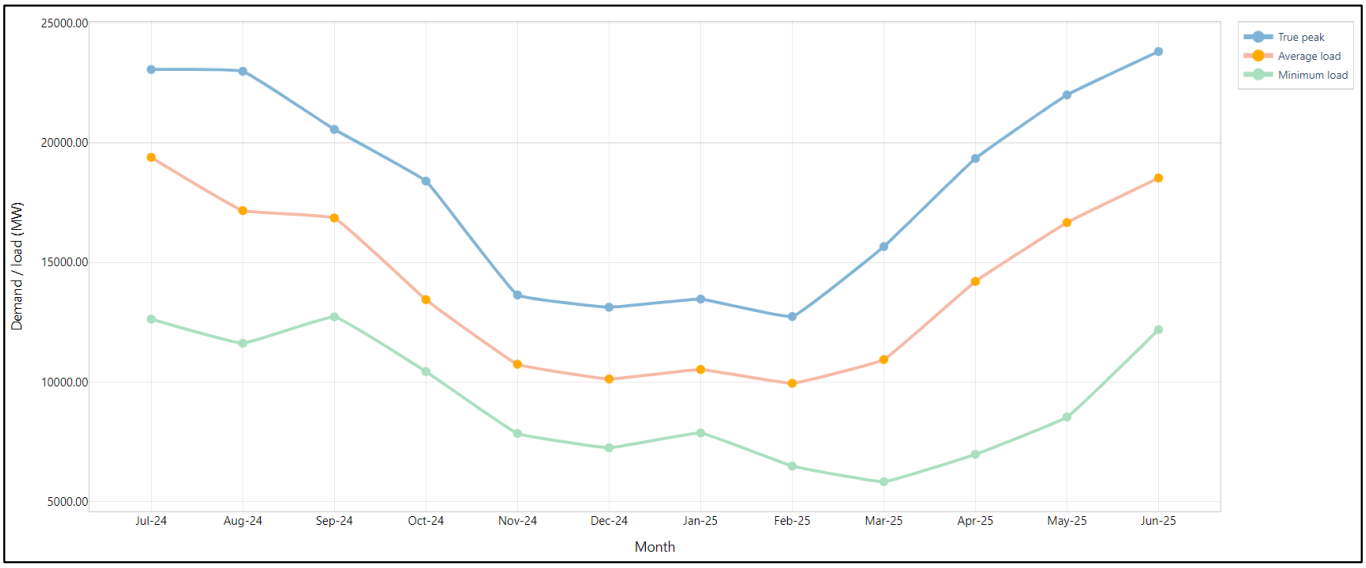


Figure 26.1. Pakistan system demand envelope, FY2024-25.

Source: Khan (2026), secondary analysis based on stated ISMO 8,760-hour demand data. Excludes K-Electric.

26.3 Selected hourly profiles show the growing importance of net load

The selected monthly-average profiles strengthen the conclusion from Chapters 15-17 that the relevant planning quantity is net load, not annual energy alone. In May 2025 the selected-hour profile falls to about 14.3 GW at H12 and rises to about 18.5 GW at H23. June shows about 15.7 GW at H12 and 21.3 GW at H23. The public source interprets this pattern in the context of cooling demand and behind-the-meter solar. Chapter 26 accepts the load-shape observation while retaining the causal attribution as a published/secondary interpretation until direct behind-the-meter output data are reconciled.

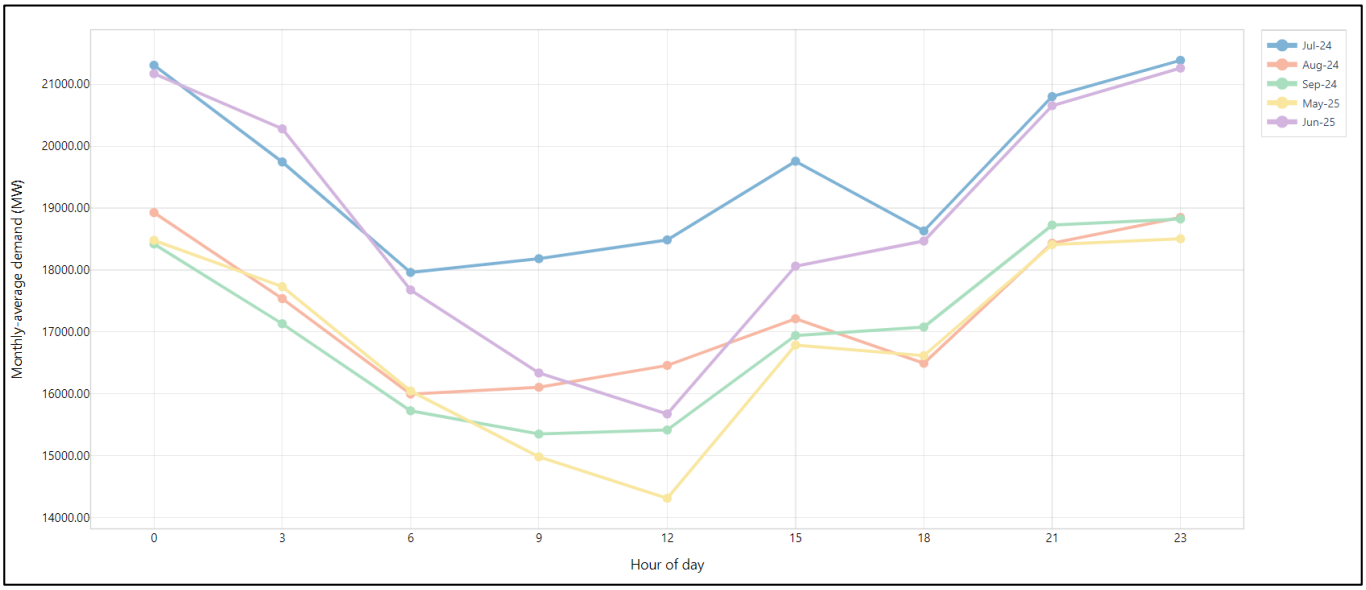


Figure 26.2. Selected monthly-average hourly demand profiles.

Source: Khan (2026), derived from stated ISMO FY2024-25 hourly demand data; selected hours only.

Table 26.2. Secondary-derived seasonal peak, trough and evening-ramp metrics.

Season	Peak hour	Peak MW	Trough MW	Ramp MW	Ramp %
Summer (Jun-Sep)	H23	20,081	16,448	3,633	22.1%
Spring (Mar-May)	H20	15,985	11,466	4,519	39.4%
Autumn (Oct-Nov)	H17	13,540	11,228	2,245	20.0%
Winter (Dec-Feb)	H18	12,367	9,511	2,856	30.0%

Source: Khan (2026), Evening Peak Demand Decomposition & Commercial Closing Scenarios. Values are secondary-derived analytics from stated ISMO/NEPRA data.

26.4 Demand response becomes a quantifiable system resource

The commercial-closing analysis provides an explicit test of a demand-side intervention. Under its calibrated load profiles and 75% switchable-commercial-load assumption, a 9 pm closing case reduces annual-average peak by 1,417 MW and summer peak by 1,913 MW, with an annual energy impact of 1,441 GWh. The 8 pm case is larger and the 10 pm case smaller. These are model cases, not observed policy outcomes, but they demonstrate why demand response should be compared against peaking generation, storage and network reinforcement on a common cost basis.

Table 26.3. Published commercial-closing demand-response model cases.

Case	Annual-avg peak reduction MW	Reduction %	Summer reduction MW	Annual energy impact GWh	Estimated saving PKR bn
8 pm close	1,663	9.4%	2,245	2,048	41-49
9 pm close	1,417	8.0%	1,913	1,441	29-35
10 pm close	1,039	6.1%	1,403	879	18-21

Source: Khan (2026). Model cases include a 75% switchable-commercial assumption and calibrated sector load shapes.

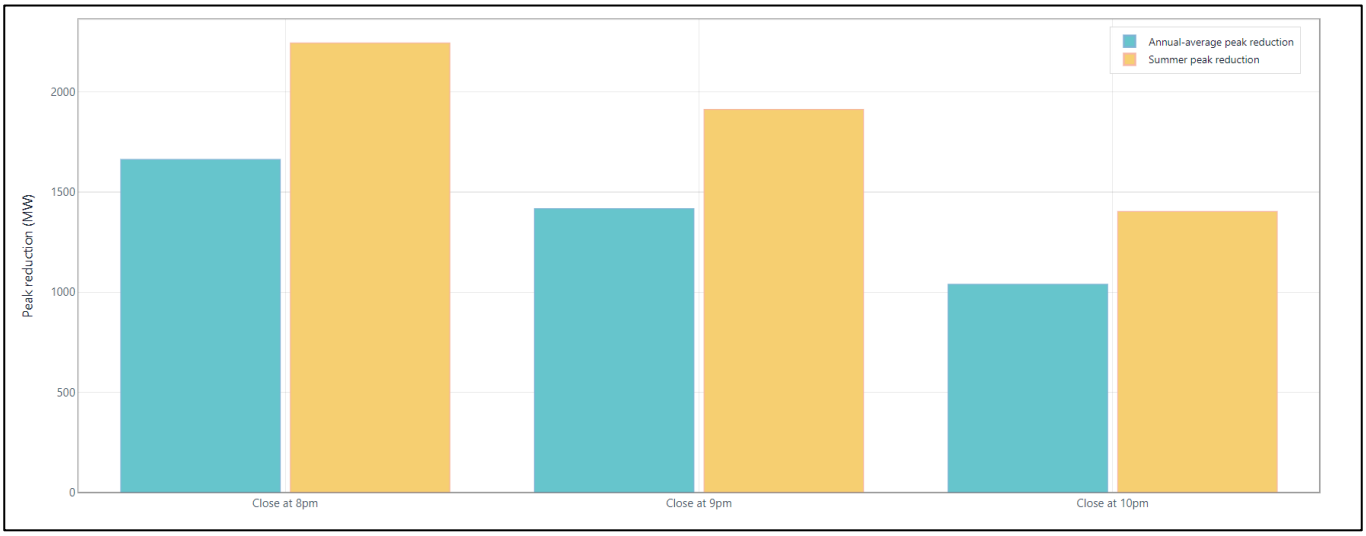


Figure 26.3. Modelled commercial-closing peak-reduction cases.

Source: Khan (2026). These are intervention scenarios, not metered policy outcomes.

26.5 Storage has observable value, but energy spread is not bankability

The same public analysis reports July evening marginal costs of 20.68, 21.91, 22.48 and 27.83 PKR/kWh for H20-H23. Using the NREL/ATB 85% round-trip-efficiency benchmark recorded in the evidence database, Chapter 26 evaluates a normalized 1 MW / 4 h battery. The four-hour average discharge-value proxy is 23.225 PKR/kWh, and the break-even charging-energy price before CAPEX, fixed O&M, degradation and service-stack value is about 19.74 PKR/kWh. Against an illustrative off-peak charging range of 4-12 PKR/kWh cited by the public analysis, the gross energy-only value is about PKR 27.0 million/year at the low charging-cost end or PKR 13.3 million/year at the high end if one complete cycle were available every day.

26.6 Boundary of the current production-cost evidence

The chronology assembled in Chapters 26-28 materially improves the evidence base, but a defensible current production-cost model still requires the original hourly load file, unit-level dispatch and outage chronology, hydropower inflow and reservoir constraints, current fuel and heat-rate series, nodal or corridor transfer limits, reserve requirements and storage service parameters. These chapters therefore advance the model from conceptual readiness to a calibrated chronological prototype, but do not relabel partial inputs as a complete unit-commitment result.

27. Representative Project Bankability Application

27.1 Why the first DCF is a prototype rather than an investment opinion

Chapter 27 applies the Brill-Viz Economics logic to the existing Safe Solar evidence case. Published inputs already held in the research database include a 10 MW case, total project cost of USD 9.275057 million, EPC cost of about USD 7.501 million, annual net energy of 18.7 GWh, requested levelized tariff of 5.48 US cents/kWh, a 75:25 debt-equity structure and a 25-year project term. The prototype then makes its remaining assumptions explicit instead of hiding them: 6% debt cost as a historical regulatory anchor, 10-year debt tenor, annual O&M equal to 1.5% of total project cost, a 14% target equity return, constant-real-USD cash flows and exclusion of taxes/pass-through items.

Table 27.1. Safe Solar DCF inputs and evidence status.

Input	Value	Evidence class	Source / status
Project cost	USD 9.275057 m	Published	Safe Solar Power, 2020
Annual energy	18.7 GWh/y	Published / project-submitted	Safe Solar Power, 2020
Requested tariff	5.48 USc/kWh	Published petition	Safe Solar Power, 2020
Debt / equity	75% / 25%	Published petition	Safe Solar Power, 2020
Model life	25 years	Published/registered	Safe Solar Power, 2020; IEA/IRENA, 2026
Debt cost	6%	Historical regulatory anchor	NEPRA, 2018
Debt tenor	10 years	Chapter 27 modelling assumption	Update required
O&M	1.5% of capex/y	Chapter 27 modelling assumption	Update required
Equity hurdle	14%	Chapter 27 modelling assumption	Update required

Source: (Safe Solar Power, 2020) Safe Solar tariff petition; (NEPRA, 2018) NEPRA tariff-benchmark guideline; (IEA/IRENA, 2026) IEA policy record. The modelling assumptions are not claimed as executed project terms.

27.2 Prototype DCF result at the requested tariff

The final Brill-Viz run retains the published/requested 5.48 US cents/kWh tariff and explicitly models the US$9.275 million development CAPEX as a construction cash outflow. The deterministic result is a project NPV of about negative US$0.246 million and project IRR of 7.67%. On the equity side, NPV is about negative US$1.42 million and IRR 8.38% against the 14% hurdle. LCOE is US$56.13/MWh, minimum debt-year DSCR is 0.863x, the equity-hurdle tariff floor is US$66.99/MWh and the DSCR-constrained bankability floor is US$73.13/MWh (7.313 US cents/kWh). The requested tariff is therefore about 1.833 US cents/kWh below the DSCR-constrained screening floor.

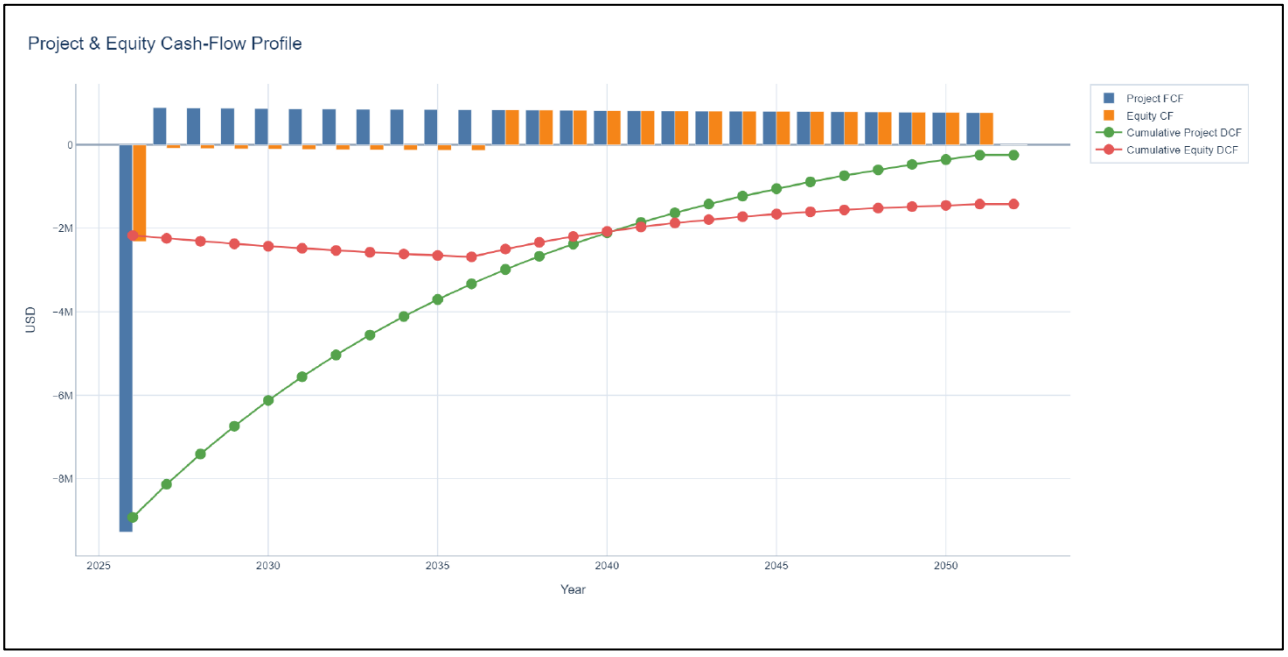


Figure 27.1. Safe Solar full-life project and equity cash-flow profile from the final Brill-Viz run.
Source: Brill-Viz Complete Economics PDF, Safe Solar 10 MW full-life run, 17 September 2026.

Table 27.2. Safe Solar prototype DCF outputs.

Metric	Final Brill-Viz prototype result
Project NPV	-US$0.246 m
Project IRR	7.67%
Equity NPV at 14% hurdle	-US$1.42 m
Equity IRR	8.38%
LCOE	US$56.13/MWh
Minimum debt-year DSCR	0.863x
DSCR-constrained tariff floor	US$73.13/MWh (7.313 USc/kWh)

27.3 Sensitivity and Monte Carlo expose the evidence that matters most

The Complete Economics report now runs one-way sensitivity, a two-way CAPEX-versus-tariff surface and a 5,000-iteration seeded Monte Carlo. The probabilistic result gives a 37.7% probability of project NPV above zero under the entered uncertainty assumptions. Project-NPV P90/P50/Mean/P10 values are about -US$1.89 million / -US$0.414 million / -US$0.317 million / +US$1.42 million. LCOE P10/P50/Mean/P90 is US$52.19/57.01/57.24/62.59 per MWh; equity-IRR P90/P50/Mean/P10 is 4.22%/8.04%/8.02%/11.89%; and minimum-DSCR P90/P50/Mean/P10 is 0.689x/0.837x/0.831x/0.964x. These distributions test the stated uncertainty ranges; they are not empirical forecasts of project success.

Table 27.3. Illustrative Safe Solar Monte Carlo summary.

Metric	Result
Iterations / seed	5,000 / 0
Probability project NPV > 0	37.7%
NPV P90 / P50 / Mean / P10	-US$1.89m / -US$0.414m / -US$0.317m / +US$1.42m
LCOE P10 / P50 / Mean / P90	52.19 / 57.01 / 57.24 / 62.59 US$/MWh
Equity IRR P90 / P50 / Mean / P10	4.22% / 8.04% / 8.02% / 11.89%
Minimum DSCR P90 / P50 / Mean / P10	0.689x / 0.837x / 0.831x / 0.964x

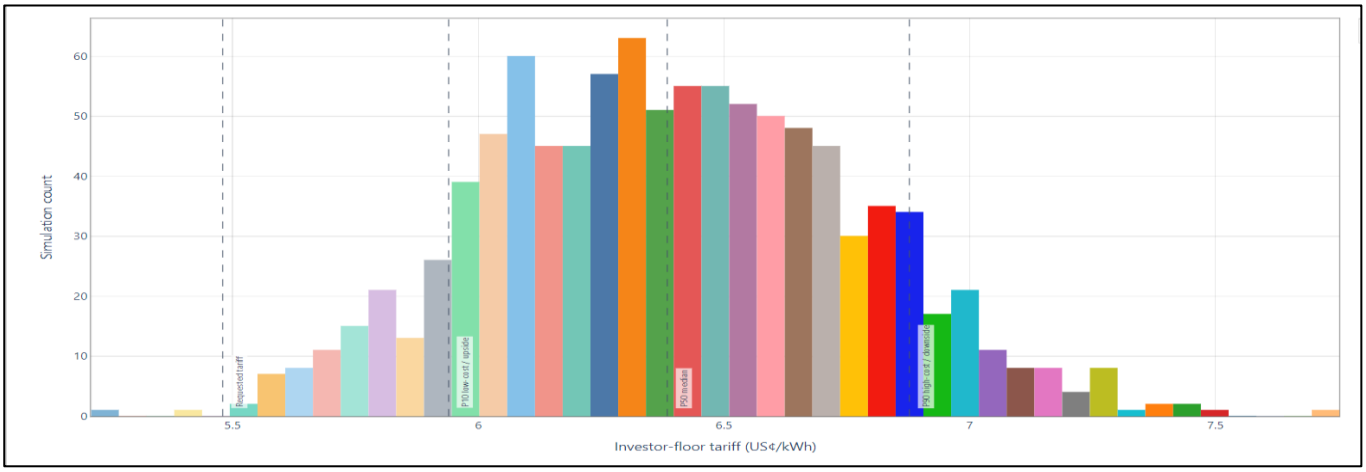


Figure 27.2. Safe Solar 5,000-run Monte Carlo distribution of project NPV.

Source: Brill-Viz Complete Economics PDF, Safe Solar 10 MW full-life run. P90/P50/P10 markers follow the report convention for higher-is-better value metrics.

27.4 The Investor-Consumer Bankability Window becomes numerically testable

Chapter 21 defines the Investor-Consumer Bankability Window conceptually, and the final Safe Solar run now supplies a consistent screening calculation. At 280.55 PKR/USD, the DSCR-constrained floor of US$73.13/MWh converts to about 20.52 PKR/kWh. The CY2026 national power-purchase-cost benchmark used by the final economics workbook is 28.88 PKR/kWh, giving a positive screening window of about 8.36 PKR/kWh. The requested historical petition tariff converts to about 15.37 PKR/kWh, while the equity-hurdle floor is about 18.79 PKR/kWh.

The positive numerical window must not be overinterpreted. The 28.88 PKR/kWh comparator is a national screening benchmark, not a project-specific locational willingness-to-pay or procurement award. A final system ceiling must include avoidable energy and capacity cost, grid and curtailment effects, reliability/capacity value, water/environment compatibility and avoided imported-fuel/FX exposure. The Safe Solar result remains a prototype, and historical/project-vintage prices for other technologies remain comparison markers rather than current offers.

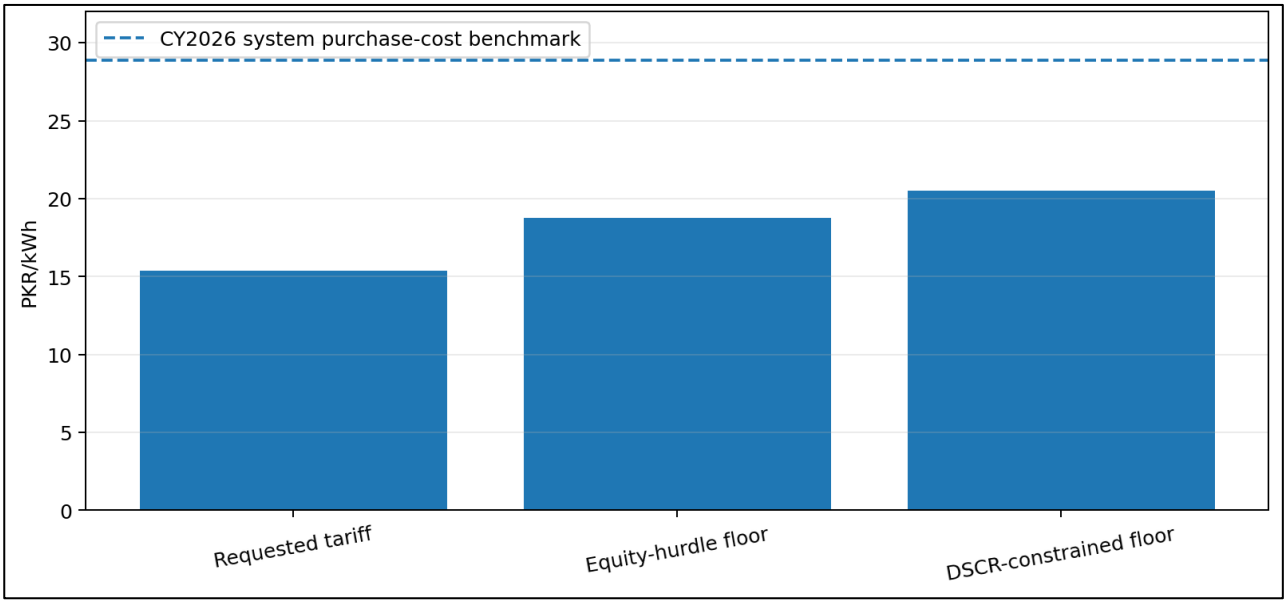


Figure 27.3. Safe Solar prototype requested tariff and investor floors relative to the CY2026 national purchase-cost benchmark.

Source: final Safe Solar Brill-Viz run and CY2026 system purchase-cost comparator in the companion economics workbook. This is a screening comparison, not a procurement recommendation.

28. Integrated Chronological and Bankability Synthesis

28.1 What the chronological evidence changes

The evidence assembled in Chapters 26-27 changes the synthesis in three practical ways. First, chronology is no longer represented only by annual demand or a few isolated peak observations: the database now contains a full monthly peak/average/minimum envelope, selected hourly shapes and seasonal ramp metrics. Second, demand response and storage are no longer treated only as qualitative enablers; they now have quantified modelled peak-reduction and energy-value proxies. Third, the Investor-Consumer Bankability Window now has a working project DCF on the investor side and an explicit, though still simplified, system purchase-cost proxy on the consumer/system side.

Table 28.1. Integrated chronological and bankability findings.

ID	Finding	Status
B8-F1	Chronology materially changes the planning problem.	Supported directionally
B8-F2	Behind-the-meter solar is likely increasing the importance of evening/late-night net load.	Partly supported
B8-F3	Demand response can substitute for meaningful peak MW in selected hours.	Supported as a model case
B8-F4	Storage has observable gross energy value but is not bankable from spread alone.	Supported
B8-F5	Representative project bankability is sensitive to financing and operating assumptions.	Supported by prototype
B8-F6	The bankability-window framework is numerically operational but not yet project-specific on the system-ceiling side.	Prototype advanced
B8-F7	A final preferred 2040/2050 MW/GWh portfolio remains premature.	Unresolved by design

28.2 The remaining gates are now narrower and more specific

Table 28.2. Residual decision gates after Chapters 26-28.

Gate	Required evidence	Why it matters
1	Primary current 8,760-hour demand/net-load file	Independently ingest and QA the original ISMO/NGC dataset.
2	Current unit-level dispatch/outages/heat rates	Required for current production-cost and unit-commitment calibration.
3	Hydro inflow and reservoir chronology	Required for dry-year, irrigation and reservoir dispatch.
4	Nodal/corridor transfer limits	Required for locational curtailment, transmission and storage siting.
5	Current fuel and FX forward paths	Required for import-risk and dispatch sensitivities.
6	Pakistan BESS/PSH CAPEX and service revenues	Required for LCOS, NPV, optimal duration and procurement tests.
7	Project/site water intensity	Required for quantitative water-constrained optimization.
8	Final representative project tariff/financing terms	Required to convert prototype investor floors into investment-grade cases.

28.3 Implication for the 2040-2050 scenario framework

The Chapter 24 scenario shares should remain screening pathways rather than preferred capacity quotas. Chapters 26-28 provide stronger evidence for three directional changes: future solar and wind should be evaluated against evening or late-night net load rather than gross annual demand; demand response should compete directly with storage and peaking capacity in least-cost tests; and storage should be placed where its energy, reserve, congestion and reliability services jointly justify cost. None of these conclusions requires fixing a national technology percentage before the full chronological model is ready.

28.4 Remaining data and model requirements

The next methodological priority is primary-data consolidation and full chronological-model implementation rather than further conceptual expansion. The key requirement is to acquire and independently ingest current 8,760-hour demand/net-load data, unit dispatch and outages, hydrology/reservoir chronology and transmission limits. A current production-cost/reliability model could then replace the prototype system ceiling with locational avoided-cost and reliability values. In parallel, final project determinations and representative hydro, thermal and storage tariff/financing cases should be reconciled so the Investor-Consumer Bankability Window can be tested across multiple technologies on a common financial-year and currency basis. These steps would strengthen the completed resource chapters and the current-system and realized-performance analyses that follow.

PART IX - CURRENT-SYSTEM CALIBRATION AND LOCATIONAL VALUE

29. Primary-Data Status and Model Readiness

29.1 Primary-data status and calibration result

Chapters 26-28 establish that the remaining obstacle to a defensible current production-cost model is primary chronological data rather than conceptual architecture. Chapter 29 therefore applies a stricter evidence test: a dataset is treated as primary only when the original current operating series is directly available and independently ingested into the study database. On that standard, the raw current 8,760-hour demand/net-load file, unit-level hourly dispatch and outage series, hydro inflow/reservoir chronology and nodal transfer-limit chronology remain open. The official ISMO system-operator portal is retained as the preferred acquisition route, while the public analytical profiles already used in this synthesis remain secondary-derived evidence recorded in the companion database (Sheets 70-72).

The absence of a complete primary 8,760-hour dataset does not invalidate the current-system calibration. Part IX materially strengthens the model where primary official evidence is available: transmission-system expansion and locational constraints, a CY2026 system purchase-cost benchmark, and project-specific 2026 tariff/indexation evidence for QASPL solar, Karot hydropower and Bhikki RLNG CCGT. The appropriate scientific treatment is to use those calibrated layers while keeping any claim of a full current 8,760-hour production-cost model explicitly gated.

Table 29.1. Primary-data status and current-system calibration summary.

Input block	Status in Part IX	New evidence	Model consequence
Raw current 8,760 demand/net load	Open	Official ISMO portal identified; secondary-derived chronology from Chapters 26-28 retained	No primary-data current chronology claim
Current unit dispatch/outages/heat rates	Open	Historical efficient-dispatch evidence only	No current unit-commitment calibration
Hydro inflow/reservoir chronology	Open	Annual/design and storage evidence only	No dry-year/reservoir optimization
Transmission constraints/reinforcement	Materially advanced	TSEP 2025-35 + KAPCO review	Locational-value framework strengthened
CY2026 system purchase cost	Closed for screening	Energy, capacity, UoSC and total PPP	Common-year screening benchmark

Input block	Status in Part IX	New evidence	Model consequence
Project tariff calibration	Advanced	QASPL, Karot and Bhikki 2026 decisions	Multi-technology current screening possible
Part IX: current-system calibration (Chapters 29-32)	Primary-data consolidation and current system/tariff calibration completed to the extent supported by public evidence	TSEP/KAPCO locational evidence, CY2026 power-purchase cost, 2026 QASPL/Karot/Bhikki tariff normalization, stronger bankability window and current full-model gate.	
Part X: realized-performance analysis (Chapters 33-38)	Observed plant/project evidence and remaining evidence closure	If primary chronology is acquired, run the production-cost/reliability model; otherwise retain the explicit 8,760-hour gate and close only source-supported resource-economics gaps.	

Source: Companion evidence database, Sheets 84-95. Open model gates remain blanks or explicit status fields, not assumed averages.

29.2 Current system cost: a better screening benchmark

NEPRA's CY2026 decision provides a materially more current system-cost reference than the FY2024-25 proxy earlier. The CY2026 forecast includes 113.582 TWh of units received and 101.324 TWh sold, with 10.87% T&D losses. On a per-kWh basis, the published power-purchase structure is 9.12 PKR/kWh energy purchase price, 17.56 PKR/kWh capacity purchase price and 2.19 PKR/kWh Use of System Charge, yielding a reported generation/power-purchase cost of 28.88 PKR/kWh (NEPRA, 2026). Capacity is therefore the largest of the three published components.

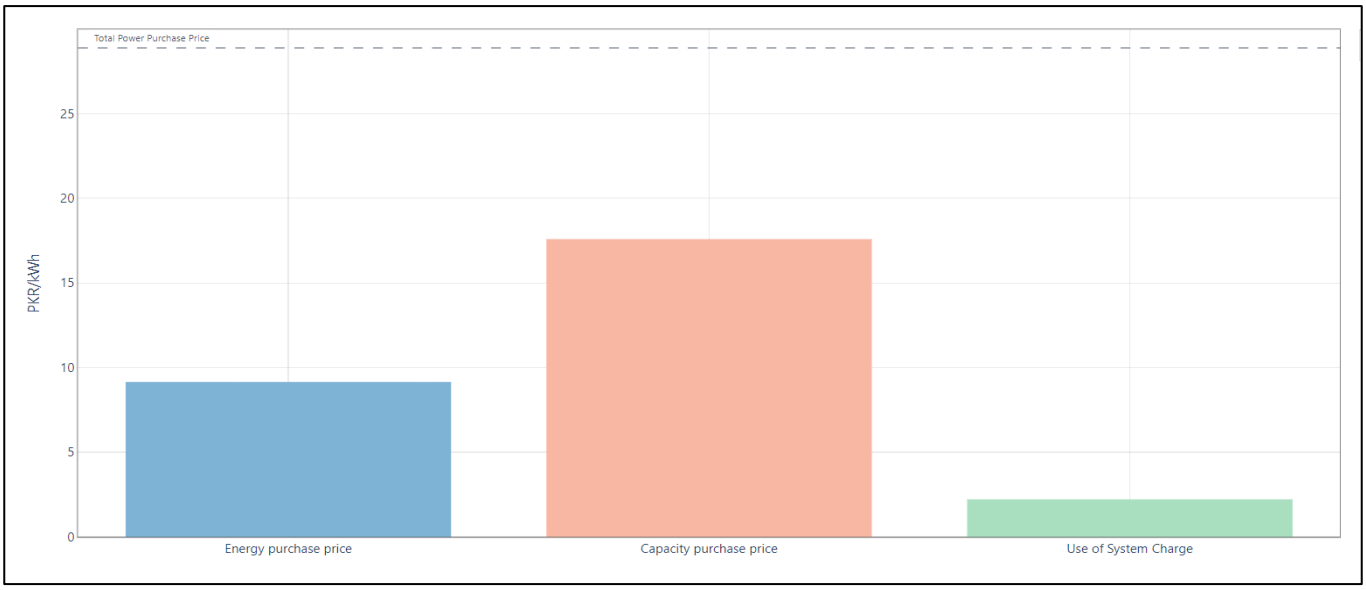


Figure 29.1. CY2026 power-purchase cost components.

Source: NEPRA (2026), CY2026 consumer-end tariff / Power Purchase Price decision. Total PPP reported as 28.88 PKR/kWh; component sum differs by rounding.

A separate HDIP FY2024-25 public-utilities balance reports 23.8% T&D losses (35.316 TWh on 148.458 TWh net supply). The 23.8% historical balance and the 10.87% CY2026 regulatory forecast are not treated as contradictory point estimates because their accounting boundaries and denominators differ. Any avoided-loss value used in the Bankability Window must therefore cite the specific loss definition applied (HDIP, 2026).

This does not mean that 28.88 PKR/kWh is what every new project can rationally be paid. It is a national-average purchase-cost forecast. The study-specific consumer/system ceiling must ultimately be based on the avoidable cost at the relevant time and location, plus reliability, capacity, congestion, transmission, import and water effects. Chapter 29 therefore uses 28.88 PKR/kWh only as a common-year screening reference while constructing that deeper locational ceiling.

30. Transmission Constraints, Locational Value and Network Investment

30.1 TSEP 2025-35 changes the economics question

The Transmission System Expansion Plan 2025-35 provides direct evidence that generation economics cannot be evaluated only at the busbar. Relative to the prior plan, the revised planning basis records delays to major hydro projects including 2,160 MW Dasu, 800 MW Mohmand and 4,500 MW Diamer Basha, while adding 3,109 MW of renewables through market-based induction. It also identifies a potential National Grid export to K-Electric of 3,456 MW by 2035 compared with an earlier 2,050 MW reference, while explicitly withholding that higher transfer from the addendum until detailed cost-comparison and reinforcement studies are completed (ISMO/NGC, TSEP 2025-35).

The same plan reports an estimated project programme of about US$5.576 billion at its assumed exchange rate, including about US$1.218 billion for transmission-line system reinforcement, US$54.94 million for transformer extension/augmentation and US$665.45 million for voltage-control and reliability improvement. These figures are planning estimates, not final procurement costs, but they establish the scale of network investment that must be included in delivered-system economics.

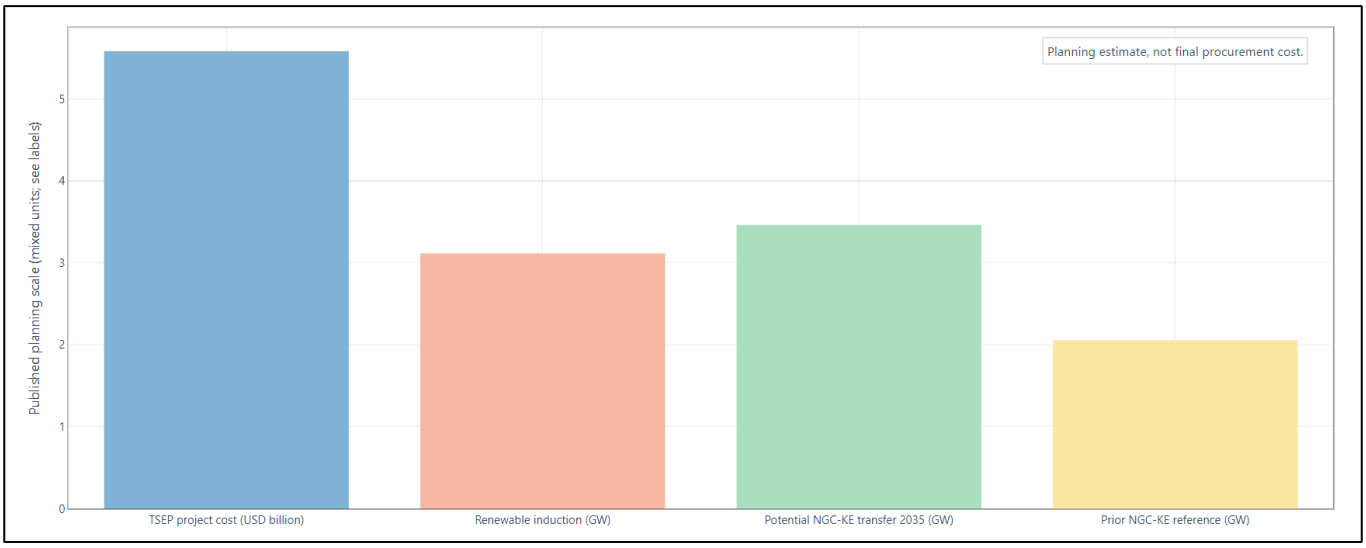


Figure 30.1. Selected grid-planning scale indicators from TSEP 2025-35.

Source: TSEP 2025-35. Units differ by indicator and are stated on the axis labels; values are planning evidence, not realized investments.

30.2 KAPCO as a locational-value case

The KAPCO tariff-review record provides a particularly useful example of why location and network condition matter. In the regulatory proceeding, NGC/ISMO identified measures intended to eliminate dependence on KAPCO or other nearby generation for secure operation: switched shunt capacitors at specified 132-kV grid stations, a third 600 MVA 500/220-kV transformer at Muzaffargarh, upgrading Vehari from 220 kV to 500 kV, and the Nagshah 220/132-kV grid station. TSEP separately states that timely completion of Vehari and Nagshah is instrumental in removing dependence of secure operation on KAPCO or other generation in the vicinity (NEPRA, 2026; TSEP 2025-35).

This evidence is important for the Investor-Consumer Bankability Window. A generator that appears expensive on energy cost alone may temporarily provide locational reliability or voltage support that the network cannot yet

substitute. Conversely, once the reinforcement is delivered, the value of retaining that generator may fall. Part IX therefore replaces the idea of one national system ceiling with a value stack: avoided energy cost, capacity/adequacy value, transmission or congestion value, voltage/reactive support, reserve/flexibility, fuel/FX security, and water/environment adjustments.

Table 30.1. Locational/system-value layers required for a final project-specific ceiling.

Value layer	What it should measure	Evidence status in this synthesis
Energy	Avoided marginal energy at the relevant hour/location	Partial; chronology available only in incomplete form
Capacity/adequacy	Avoided capacity or reliability requirement	Not yet quantified with LOLE/EENS
Transmission/congestion	Avoided/deferred reinforcement or congestion	Current process evidence acquired from TSEP/KAPCO
Voltage/reactive	Avoided out-of-merit generation / voltage support	Current process evidence acquired
Reserve/flexibility	Avoided reserve shortage and ramp cost	Historical quantified evidence only
Fuel/FX security	Imported fuel displaced and FX exposure avoided	Partial; current RLNG price acquired
Water/environment	Water scarcity and compliance adjustment	Framework only; site m3/MWh still incomplete

31. CY2026 Tariff and Multi-Technology Calibration

31.1 Why current indexed evidence matters

Chapters 18-21 show that historical levelized tariffs are useful for project architecture but can be misleading when treated as current economics. Part IX demonstrates this directly using 2026 project decisions with different structures and indexation drivers: QASPL expresses current components in PKR/kWh; Karot combines variable PKR/kWh charges with fixed PKR/kW/month charges; and Bhikki combines capacity PKR/kW/h with variable O&M and a separate fuel component.

Table 31.1. Current/common-basis screening values used in Part IX.

Case	Price/floor basis	Screening value (PKR/kWh)	Evidence caution
CY2026 system	Official power-purchase-price forecast	28.88	National average, not project-specific ceiling
QASPL solar	Jan-Mar 2026 indexed tariff	17.71	Legacy 2015-vintage solar project
Safe Solar	DSCR-constrained prototype tariff floor	20.52	Final Brill-Viz prototype; final tariff/financing still not reconciled
Karot hydro	Jan-Mar 2026 indexed equivalent	25.89	Uses design annual energy to convert fixed charge
Bhikki RLNG	Fuel + VOM + capacity at 92% availability	22.07	Screening structural proxy, not actual invoice
Bhikki RLNG	Fuel + VOM + capacity at 42.5% utilization	24.91	System-utilization stress test, not plant observed dispatch
Nishat RFO	Jan-2026 NEPRA fuel-cost component only	36.82	Fuel component only; not total tariff/LCOE or a like-for-like project screening price

Sources: NEPRA CY2026 decision; NEPRA QASPL, Karot and QATPL Jan-Mar 2026 decisions; PPIB Bhikki/Karot project evidence; Safe Solar DCF in Chapter 27. Values are evidence-class tagged and are not all investor floors.

Foreign O&M, ROE, debt service and fuel are exposed to combinations of exchange rate, CPI, SOFR, KIBOR and commodity price. A current comparison therefore requires both time normalization and tariff-structure normalization.

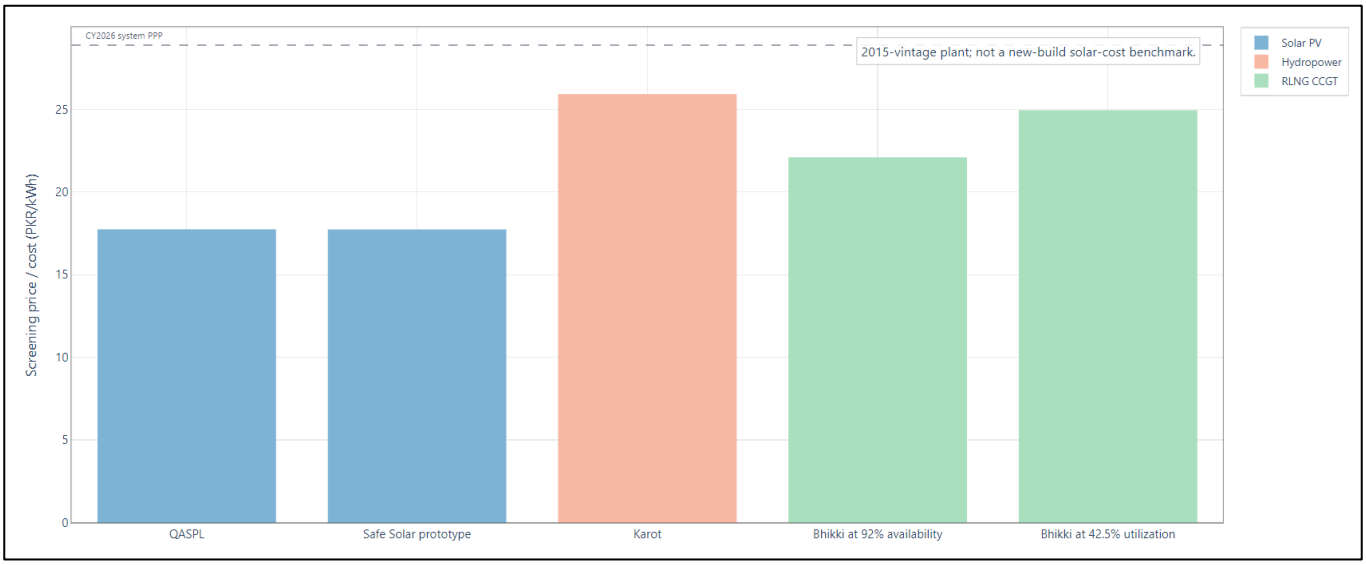


Figure 31.1. Current/common-basis screening against CY2026 power-purchase cost.

Source: Companion evidence database, current-system calibration sheets. The CY2026 system PPP is a screening reference, not the final locational consumer/system ceiling.

31.2 QASPL solar: current tariff versus new-build cost

For January-March 2026, QASPL's indexed tariff components are 0.9945 PKR/kWh fixed O&M-local, 7.7592 PKR/kWh fixed O&M-foreign and 8.9580 PKR/kWh return on equity, totalling 17.7117 PKR/kWh. The same decision uses an exchange-rate indexation value of 280.55 PKR/USD and US and Pakistan CPI indices. This is valuable current tariff evidence, but QASPL was commissioned in 2015 and carries legacy project structure; it should not be presented as the cost of a new solar plant in 2026.

31.3 Karot hydropower: fixed charges dominate the equivalent

Karot's January-March 2026 indexed decision reports variable components totaling 0.7482 PKR/kWh and fixed components totaling about 9,328.18 PKR/kW/month. Using the decision's 712.8 MW net capacity and the study's published 3,174 GWh annual design energy, the calculation in Chapter 31 gives an equivalent current screening tariff of about 25.89 PKR/kWh. This is not actual 2026 realized unit cost: it deliberately uses design annual energy because current matched generation has not yet been acquired, and NEPRA states that the indexation remains provisional pending the final COD adjustment.

31.4 Bhikki RLNG: utilization changes the capacity burden

Bhikki's January-March 2026 decision reports a 2.2474 PKR/kW/h RLNG capacity charge, 0.3617 PKR/kWh variable O&M and an RLNG price of 3,477.12 PKR/MMBtu. Combining the fuel price with PPIB's 61.59% net efficiency gives a derived fuel-energy proxy of about 19.26 PKR/kWh. If the capacity charge is spread over 92% annual availability, the resulting structural screening value is about 22.07 PKR/kWh; if it is spread over the FY2024-25 thermal-fleet utilization proxy of 42.5%, it rises to about 24.91 PKR/kWh. The second case is a stress test, not a claim about Bhikki's actual 2026 utilization or billing.

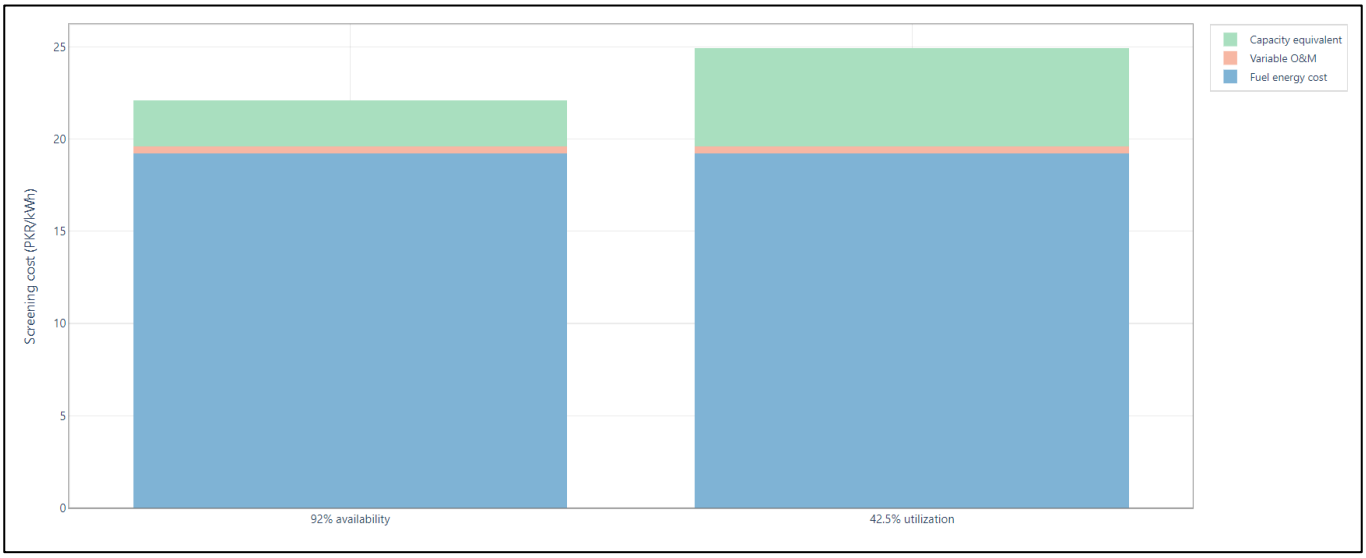


Figure 31.2. Bhikki RLNG screening cost under alternative utilization assumptions.

Sources: NEPRA QATPL Jan-Mar 2026 tariff decision; PPIB Bhikki project efficiency/availability; NEPRA FY2024-25 thermal-fleet utilization. Derived for the Chapter 31 screening comparison only.

31.5 Safe Solar DCF: investor floor remains a prototype

The Safe Solar DCF in Chapter 27 remains the only representative case in this synthesis with Full-DCF evidence gate = Yes. In the final Brill-Viz run, the requested tariff is 5.48 US cents/kWh, project NPV is about negative US$0.246 million, equity IRR is 8.38% against the 14% hurdle, minimum debt-year DSCR is 0.863x, and the DSCR-constrained bankability floor is US$73.13/MWh (7.313 US cents/kWh). At 280.55 PKR/USD that floor is about 20.52 PKR/kWh. The case remains a research prototype rather than an investment-grade conclusion because final/current tariff, executed financing and several operating inputs remain unresolved.

32. Current-System Synthesis

32.1 Investor-Consumer Bankability Window: materially stronger, still provisional

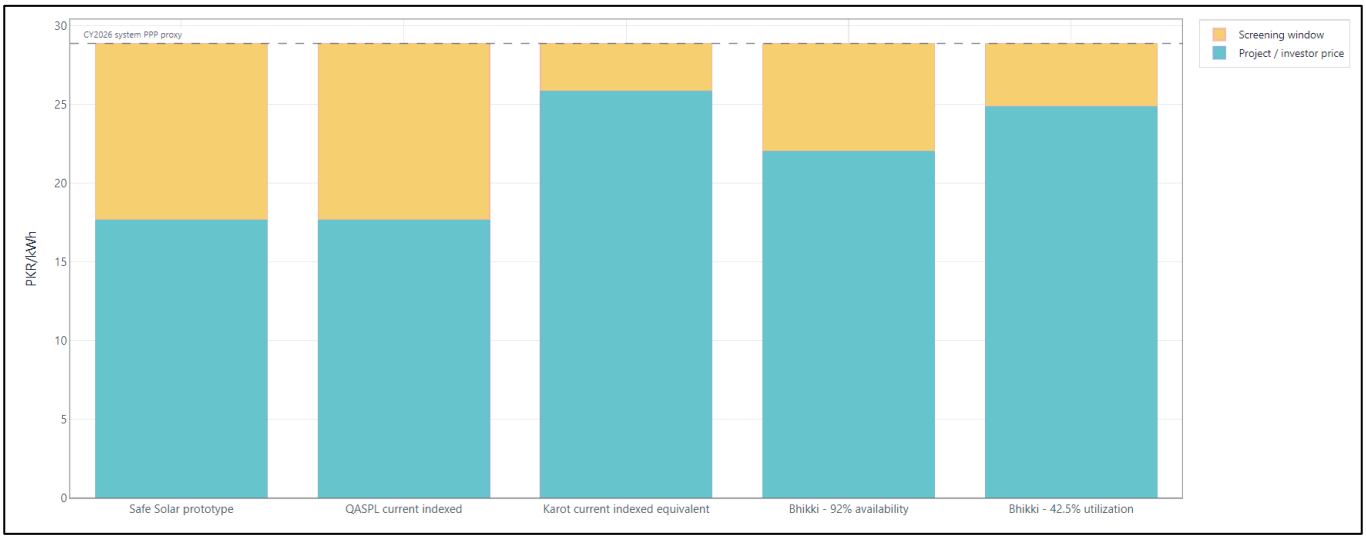


Figure 32.1. Prototype current-system screening windows relative to the CY2026 national purchase-cost proxy.

Source: Companion evidence database, current-system calibration sheets. Positive screening gaps identify cases for deeper project/system modelling; they are not investment recommendations.

Using the CY2026 power-purchase cost of 28.88 PKR/kWh as a common screening reference produces positive numerical gaps of about 8.36 PKR/kWh for the final Safe Solar DSCR-constrained prototype floor, 11.17 for QASPL's current indexed tariff, 2.99 for the Karot equivalent, 6.81 for Bhikki at 92% availability and 3.97 for the Bhikki 42.5% utilization stress case. These gaps do not mean that every project is automatically affordable or investable. The values are not identical evidence classes, and 28.88 PKR/kWh is not the final locational system ceiling.

32.2 Current-system conclusions

Table 32.1. Current-system integrated findings and evidence status.

ID	Finding	Status
B9-F1	Primary current 8,760-hour data gate remains open.	Unresolved by design
B9-F2	Transmission constraints create locational reliability value not visible in plant LCOE.	Supported
B9-F3	CY2026 system purchase cost is capacity-heavy.	Supported
B9-F4	Current economics cannot be inferred from historical levelized tariffs.	Supported
B9-F5	Low utilization increases the effective per-kWh burden of capacity-based thermal tariffs.	Supported as screening derivation
B9-F6	The bankability window is stronger when project and system evidence share a current time basis.	Prototype materially strengthened
B9-F7	The final system ceiling must be locational and service-specific.	Supported conceptually with current evidence
B9-F8	2040/2050 MW and GWh ranges should not yet be frozen.	Unresolved by design

32.3 Resource-economics implications

The current-system calibration improves the common system-economics basis used to interpret the completed Coal/Oil/Gas, Nuclear and Bioenergy/Waste chapters, but it does not convert uneven evidence into decision-grade economics. Coal/oil/gas has a strong national baseline, current RLNG calibration and now a current RFO fuel-cost calibration. The RFO addition closes a fuel-cost evidence gap but not the all-in plant-economics gap; selected coal tariff/fuel annexes and common water/emissions normalization also remain incomplete. Nuclear has strong operating performance and C-5 PC-I cost evidence, but current project tariff/financing and cooling-water economics remain incomplete. Bioenergy has operating bagasse evidence but still lacks a harmonized provincial feedstock/waste-flow dataset and representative current DCF case. Chapters 12-14 therefore retain these limitations explicitly, while Chapters 34-36 add realized-performance evidence where available.

32.4 Remaining resource-economics requirements

The evidence boundary for the remaining analysis is conditional on data availability. If the primary hourly and operating datasets become available, the next step is a genuine current 8,760-hour production-cost/reliability model with unit dispatch, outages, hydro chronology, nodal transfer constraints, reserves and storage. If those files remain inaccessible, the priority is to close the highest-value gaps that do not require fabrication: selected current coal tariff/fuel cases, complete current RFO tariff/O&M/remaining-life finance and dispatch evidence, nuclear financing/water evidence, bioenergy feedstock/economics, matched Karot and Bhikki generation/dispatch, and project-specific storage costs. Only after the chronological and project-economics gates converge should the manuscript publish preferred 2040/2050 MW/GWh ranges or treat the Investor-Consumer Bankability Window as project-decision grade.

32.5 Current-system evidence boundary

Part IX completes the transmission/system-cost and multi-technology tariff calibration that can be supported by official public evidence while preserving the primary 8,760-hour gate. The subsequent realized-performance chapters therefore add only evidence that can be derived defensibly from observed plant, project and regulatory records; they do not invent missing hourly operating inputs.

Table 32.5. Current-system evidence boundary: analytical stages, primary deliverables and scope.

Analytical stage / manuscript location	Primary deliverable	Scope
Geothermal/resource evidence synthesis (Chapters 7-8)	Geothermal / hydrothermal evidence synthesis	Global resource systems, Pakistan inventory, Zindapir, other prospects, direct use, EGS context and staged exploration programme.
Project-economics evidence base (Chapters 18-21)	Pakistan project-economics database	Tariff determinations, EPC/project costs, O&M, financing, infrastructure, fuel, water and performance.
Resource and spatial evidence (Chapters 9-14 and 22)	Hydro-water and solar-wind spatial datasets	Seasonality, resource zones, transmission, complementarity, pumped-storage screening and resource-specific evidence.
Comparative economics analysis (Chapters 18-21)	Common Brill-Viz economic cases	Evidence-normalized solar, wind, hydro, geothermal, nuclear, coal, RLNG, storage and hybrid cases; system-cost layer and economics readiness.
Regional portfolio evidence (Chapter 22)	Regional Pakistan portfolios	Evidence-backed screening portfolios for Punjab, Sindh, Balochistan, KP, GB and AJK with water/grid/resource constraints.
Scenario framework and roadmap (Chapters 24-25)	2030/2040/2050 scenario screening and integrated roadmap	ISP-anchored published demand/capacity baseline; post-2035 screening pathways; flexibility stress tests; decision gates and adaptive roadmap.
System integration and global comparators (Chapters 15-17 and 23)	Chronological/flexibility evidence and global functional comparators	Published load/dispatch/flexibility evidence, model-readiness gate and transferable comparator lessons.
Chronological and bankability application (Chapters 26-28)	Chronological evidence and representative project bankability	Monthly/hourly profile evidence, demand response, prototype DCF/Monte Carlo and Investor-Consumer Bankability Window application.

PART X - REALIZED RESOURCE ECONOMICS AND INTEGRATED SYNTHESIS

33. FY2024-25 Realized Plant Economics and Utilization

33.1 Why realized annual performance changes the comparison

The earlier economics and scenario chapters deliberately avoid treating historical levelized tariffs or modelled screening prices as if they were current realized system costs. Part X adds a different evidence layer: NEPRA's FY2024-25 plant-level net generation, utilization, capacity purchase payments, energy purchase payments and, where reported, supplemental charges. Dividing those annual payments by net delivered energy produces an observed annual procurement-cost proxy. This is not LCOE, not a project IRR, and not a forecast tariff. It is a same-year system-payment intensity that helps explain how utilization changes the cost burden of capacity-based contracts.

The resulting cross-technology comparison is useful precisely because it exposes a recurring Pakistan-specific issue: capacity cost per delivered kWh rises sharply when contracted assets generate little energy. Conversely, high utilization can spread fixed obligations across more output. This does not make utilization the only decision variable; fuel exposure, water, emissions, reliability, flexibility and network value remain separate constraints.

The Energy Yearbook provides an independent annual cross-check for two cases already used in the NEPRA-derived economics layer. HDIP reports Karot at 720 MW, 2,738.19 GWh and 43.30% utilization, closely matching the ~2.74 TWh / 43.4% evidence used here. It also reports Quaid-e-Azam Thermal Power (Bhikki) at 1,180 MW and 6,098.15 GWh, broadly matching the ~6.10 TWh annual generation in the NEPRA calibration. This cross-source agreement strengthens the annual operating evidence while preserving differences between gross/net generation and reference-capacity definitions (HDIP, 2026; NEPRA, 2026).

Table 33.1. Selected FY2024-25 operating and procurement-cost evidence.

Case	FY2024-25 utilization	Net generation	Observed procurement-cost proxy	Evidence note
Local Thar coal	72.9%	15.55 TWh	30.10 PKR/kWh	Portfolio total; CPP+EPP.
Imported coal	22.9%	8.70 TWh	65.61 PKR/kWh	Portfolio total; CPP+EPP+PLAC.
Nuclear	78.5%	22.45 TWh	18.49 PKR/kWh	Fleet total; CPP+EPP.
Bagasse	30.1%	0.67 TWh	32.33 PKR/kWh	Portfolio total; CPP+EPP.
Bhikki RLNG	61.6%	6.10 TWh	28.10 PKR/kWh	Plant; CPP+EPP+PLAC.
Karot hydropower	43.4%	2.74 TWh	37.78 PKR/kWh	Plant; CPP+EPP.

Source: NEPRA (2026), Performance Evaluation Report of Operational Power Plants FY2024-25 (utilization factor % of theoretical full-capacity annual generation). Cost proxies are study derivations from reported annual payment and net-generation values. They should not be compared with plant LCOE without preserving the different contractual and system-service structures.

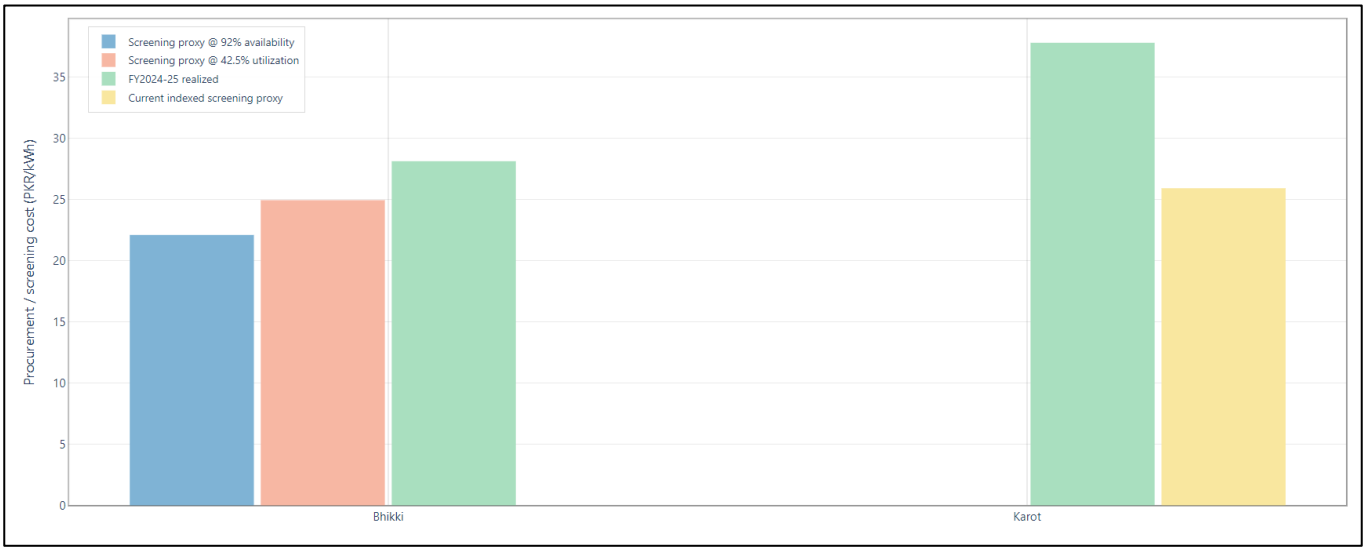


Figure 33.1. Current-system screening proxies compared with FY2024-25 realized annual procurement-cost proxies for Bhikki and Karot.

34. Coal, Oil and Gas Evidence

34.1 Local versus imported coal: an observed FY2024-25 contrast

The FY2024-25 coal evidence is more informative than a simple indigenous-versus-imported fuel argument. The four local Thar-coal plants in NEPRA's annual performance dataset had a combined reference capacity of 2,433 MW, generated about 15.55 TWh and operated at a 72.9% utilization factor. The four imported-coal plants had 4,342 MW of reference capacity, generated about 8.70 TWh and operated at only 22.9% utilization. The derived all-in annual procurement-cost proxy is about 30.10 PKR/kWh for the local-coal portfolio and 65.61 PKR/kWh for the imported-coal portfolio.

The Yearbook is used cautiously at plant level. Its thermal-station table reports 9,104.42 GWh against a stated 660 MW for Engro PowerGen Thar, which would exceed the theoretical 5,781.6 GWh annual maximum at continuous full output. That individual entry is therefore flagged as an internal source/table-alignment anomaly and is excluded from plant capacity-factor or economic calculations until reconciled. The coal portfolio economics in this synthesis continue to use the internally consistent NEPRA plant-performance dataset, while the Yearbook is used for national coal reserves, production, imports and import-bill context (HDIP, 2026; NEPRA, 2026).

The decomposition is crucial. Local coal's capacity-payment intensity is about 16.47 PKR/kWh, whereas imported coal's is about 47.58 PKR/kWh. The observed difference therefore reflects much more than fuel price. It demonstrates the cost of maintaining low-utilization contracted capacity. This is strong evidence for the synthesis hypothesis that Pakistan should compare technologies at system level rather than by headline fuel price alone.

Table 34.1. Local and imported coal annual system-payment comparison, FY2024-25.

Coal group	Reference capacity	Net generation	Utilization	Capacity proxy PKR/kWh	Energy+supplemental proxy	Total proxy PKR/kWh
Local Thar coal	2,433 MW	15.55 TWh	72.9%	16.47	13.63	30.10
Imported coal	4,342 MW	8.70 TWh	22.9%	47.58	18.03	65.61

The local-versus-imported coal utilization and procurement-cost comparisons are shown in Figures 12.1 and 12.2 (Chapter 12) and are not repeated here.

34.2 What this does and does not prove

The evidence supports a narrower conclusion than 'local coal is always cheaper'. It shows that, in FY2024-25, the local Thar-coal portfolio combined much higher utilization with substantially lower annual payment intensity per delivered kWh than the imported-coal portfolio. It does not settle future mine expansion cost, plant refurbishment, water demand, air pollution, carbon exposure, ash management, transmission requirements or financing. Current NEPRA tariff registers also show that Thar-coal fuel and other components continue to be adjusted through 2026. Coal therefore remains an indigenous security option to be tested conditionally, not a predetermined national end-state.

The 2022 Outlook had anticipated rising local and Thar coal use and modelled partial substitution of imported coal partly for foreign-exchange savings. FY2024-25 realized performance now provides a stronger test than national fuel-share arguments alone. It supports examining indigenous coal as an energy-security option, but it also shows that utilization and contracted capacity payments can dominate delivered annual cost. The older forecast is therefore used as a hypothesis-generating planning source, not as proof that future coal expansion is economically optimal (Ministry of Planning, Development & Special Initiatives, 2022).

34.3 RLNG and the value of observed utilization

Bhikki provides a useful calibration case. Chapter 31 derives structural screening values from the January-March 2026 tariff components, while Chapter 34 adds FY2024-25 observed annual generation and system payments: 6.10 TWh at 61.6% utilization, with CPP of PKR 18.064 billion, EPP of PKR 141.488 billion and PLAC of PKR 11.788 billion. The derived annual procurement-cost proxy is about 28.10 PKR/kWh. This is higher than the Chapter 31 structural proxy at 92% availability and illustrates why actual dispatch, fuel use and system conditions must be reconciled before project economics are interpreted. This plant-level result should be read alongside the national external-account exposure: LNG imports during July-March FY2026 were still roughly US$1.9 billion, so RLNG dispatch carries a material fuel-price and foreign-exchange risk even when plant efficiency is strong (Government of Pakistan, 2026).

34.4 RFO: current fuel-cost evidence makes liquid-fuel exposure explicit

RFO is not only a historical issue. PPIB's operational list at 30 June 2026 still contains six RFO IPPs totaling about 1,116 MW. Nishat Power is a useful representative case because plant identity, capacity and fuel are explicit and NEPRA publishes current fuel-price adjustments. In January 2026, the approved Nishat RFO fuel-cost component was PKR 36.8213/kWh at a revised RFO price of PKR 187,191.14/MT. FY2024-25 plant-performance evidence records only about 5.15% utilization and 87.99 GWh net generation for Nishat Power, showing that fuel cost and dispatch/utilization must be interpreted together (PPIB, 2026; NEPRA, 2026).

This evidence supports a narrower analytical conclusion than either retaining or retiring RFO capacity as a blanket rule. Existing RFO assets can be tested against their actual fuel/levy/FX burden, capacity and reliability service, remaining contractual obligations, dispatch frequency and the cost of alternatives. The current evidence is sufficient for fuel-cost and uncertainty screening but not for a complete remaining-life DCF because current all-in tariff components, O&M, remaining financing and hourly dispatch have not yet been reconciled.

35. Nuclear Economics, C-5 and Water Interface

35.1 Current fleet economics are not uniform

Pakistan's nuclear fleet generated about 22.45 TWh in FY2024-25 at a reported aggregate utilization factor of 78.5%. The derived fleet-average CPP+EPP procurement-cost proxy is about 18.49 PKR/kWh, below the FY2024-25 system purchase-cost proxy used earlier in the synthesis. The unit-level evidence, however, varies materially. K-2 combines 83.6% utilization with a derived annual proxy near 10.39 PKR/kWh, while K-3 combines 63.5% utilization with a proxy near 31.79 PKR/kWh. The Chashma units range roughly from 11.50 to 22.27 PKR/kWh in the same calculation.

This spread is analytically important. Nuclear should not be represented by one generic global LCOE or by one Pakistan fleet average. Unit age, capital recovery, financing and utilization materially affect system payment intensity.

The unit-level nuclear utilization versus procurement-cost comparison is shown in Figure 13.1 (Chapter 13) and is not repeated here.

35.2 C-5: capital intensity and financing evidence

The approved C-5 PC-I reports a total rationalized cost of PKR 1,047,988.84 million, gross/net capacity of 1,100/1,017.5 MW, an 81-month implementation period, FEC of PKR 187,098.96 million and Chinese supplier credit/foreign aid of PKR 820,742.99 million. On the PC-I gross-capacity definition, the approved cost is about PKR 952,717/kW; on net capacity it is about PKR 1.030 million/kW. These are capital-intensity measures, not a tariff or an NPV.

The supplier-credit amount is about 78.3% of total approved PC-I cost, while the FEC field is about 17.9%. The document reports those categories separately and they should not be silently treated as equivalent accounting definitions. The remaining bankability gap is the study-specific tariff, debt service and final financing structure after commissioning.

35.3 Chashma cooling-water evidence: withdrawal is not consumption

WAPDA's FY2022-23 annual report provides an important water-system observation. It reports 1.960 MAF of water supplied for cooling requirements of the Chashma Nuclear Power Plant, with the water ultimately returning to the river. It also reports a continuous 3,540-cusec CJ-Link Canal supply to PAEC for C1-C4. The 1.960 MAF figure is approximately 2.42 billion cubic metres of annual water supply.

This is a large physical water interface, but it is not evidence of 2.42 billion cubic metres of consumptive use. The synthesis must distinguish withdrawal, return flow, evaporative consumption and water quality. It also must not treat the C1-C4 operating supply as the C-5 design requirement. Chapter 35 therefore strengthens the nuclear-water evidence while retaining the study-specific consumptive-use gap.

Table 35.1. C-5 investment and Chashma water-interface evidence.

Metric	Reported value	Interpretive caution
C-5 approved cost	PKR 1,047,988.84 million	Planning Commission PC-I
Gross / net capacity	1,100 / 1,017.5 MW	PC-I definition
Chinese supplier credit / foreign aid	PKR 820,742.99 million	PC-I reported field
FY2022-23 cooling-water supply to Chashma	1.960 MAF/year	WAPDA; ultimately returned to river
Continuous CJ-Link supply to C1-C4	3,540 cusecs	WAPDA

36. Bioenergy and Waste

36.1 Bagasse is an operating portfolio, not a theoretical category

Pakistan's bagasse fleet is now supported by plant-level operating evidence. NEPRA reports 302 MW installed and 254 MW reference capacity across the listed bagasse plants in FY2024-25, with 670 GWh of net generation and a portfolio utilization factor of 30.1%. The derived portfolio CPP+EPP procurement-cost proxy is about 32.33 PKR/kWh.

The portfolio average hides extreme heterogeneity. JDW-II and JDW-III operated at about 89.8% and 85.8% utilization, whereas Chanar and Shahtaj were close to 1-2% in the annual dataset. This means a national bioenergy scenario should not assign one uniform capacity factor to all bagasse projects. Feedstock strategy, cogeneration configuration, industrial steam demand, operating season and off-season fuel arrangements matter.

The plant-level bagasse/cogeneration utilization comparison is shown in Figure 14.1 (Chapter 14) and is not repeated here.

36.2 Representative project-cost architecture

PPIB project pages provide a consistent historical capital-structure family for several commissioned bagasse projects. Hamza, RYK, Layyah, Chanar and Almoiz are reported with 80:20 debt-equity structures and 45% annual availability assumptions. Their project prices span approximately US$14.95 million for 15 MW to US$40.86 million for 41 MW, or roughly US$0.996-0.997 million/MW for most of the selected cases. These historical cases are useful for cost architecture and Brill-Viz Economics testing, but they are not current new-build bids.

Pakistan's 2025-26 sugarcane production of 89.45 million tonnes confirms the scale of the underlying agro-industrial feedstock base. It does not, by itself, establish recoverable bagasse tonnage or power potential. A final national bagasse resource estimate would require a sourced residue ratio, moisture/energy content, mill self-use, alternative bagasse uses and seasonal logistics. Chapter 36 therefore closes the operating-performance discussion without manufacturing a national bioenergy potential number.

Table 36.1. Representative PPIB bagasse project-economics evidence.

Project	Gross capacity	Historical project cost	Debt:Equity	Published annual availability
Hamza Sugar Mills	15 MW	US$14.949m	80:20	45%
RYK Mills	30 MW	US$29.898m	80:20	45%
Layyah / Thal Industries	41 MW	US$40.861m	80:20	45%
Chanar Energy	22 MW	US$21.925m	80:20	45%
Almoiz Industries	36 MW	US$35.878m	80:20	45%

37. Pakistan Storage Investment Evidence

37.1 From generic battery assumptions to a Pakistan transmission project

Earlier storage sections treated battery storage conservatively because Pakistan-specific procurement CAPEX and revenue-stack evidence were incomplete. ADB's 2026 proposed Grid-Integrated Battery Energy Storage System for Stability and Resilience Project now provides a concrete development-scale case. Preliminary feasibility work identifies two installations along the north-south transmission corridor, each approximately 500 MW / 1,000 MWh, giving a combined scale of about 1,000 MW / 2,000 MWh and a two-hour duration.

The study is explicitly designed for optimized dispatch, ancillary services, congestion relief, renewable-energy transmission, frequency and voltage support. This strongly supports the synthesis treatment of storage as a system-service asset rather than a simple energy-arbitrage device.

ADB lists US$50 million of concessional ordinary capital resources lending plus US$200 million of ordinary capital resources, a US$250 million lending envelope. Dividing that financing envelope by the proposed storage scale gives US$250/kW and US$125/kWh, but these are financing-envelope intensities, not verified total installed costs. The full project CAPEX, degradation/replacement assumptions, procurement prices and market revenue stack remain required for LCOS, NPV or IRR.

Table 37.1. ADB proposed Pakistan grid-integrated BESS case.

Metric	Evidence	Caution / use
Status	Proposed	Not commissioned
Scale	~1,000 MW / 2,000 MWh	Two ~500 MW / 1,000 MWh sites
Duration	~2 hours	Derived from reported MW/MWh
ADB lending envelope	US$250 million	Not necessarily total CAPEX

Primary services	Dispatch, ancillary services, congestion relief, RE integration, frequency/voltage support	System-value stack

38. Integrated Conclusions and Evidence Limits

38.1 Integrated evidence position

The evidence assembled in Parts I-X supports an integrated assessment of Pakistan's energy system across resource availability, current production and utilization, electricity generation and consumption, water constraints, transmission, project economics, financing, import exposure and system efficiency. The resource-specific synthesis in Chapters 8-14 is complemented by the current-system and realized operating-economic evidence developed in Chapters 29-37.

The evidence sources perform different functions within this framework. The **Pakistan Energy Yearbook 2024-25** provides the principal complete annual statistical bridge for recent national energy production, imports, electricity generation, consumption and selected plant-performance indicators. The **Pakistan Economic Survey 2025-26** provides a later partial-year/current snapshot. The **Ministry of Energy Year Book 2023-24** provides administrative and implementation context, while the **Pakistan Energy Outlook 2021-2030** is retained as a historical official planning and forecast benchmark. Peer-reviewed and analytical literature, including **Kanwal, Khan and Rauf (2020)** and **Khan, M. R. (2024)**, contributes resource, infrastructure and comparative interpretations but does not replace current official statistical evidence.

This separation is important because measured observations, administrative records, published forecasts, analytical interpretations, derived calculations and forward scenarios answer different questions and should not be combined as though they represent the same evidence class.

38.2 What the integrated evidence establishes

Three system-level findings become particularly clear when the resource, Yearbook, regulatory and economic evidence are considered together.

First, **system efficiency and network performance are energy resources in their own right**. FY2024-25 public-utilities transmission and distribution losses were reported at approximately 35.3 TWh. The magnitude does not imply that all losses are technically or economically recoverable, but it establishes that network reinforcement, metering, commercial-loss reduction, efficiency and demand management must be assessed alongside new generation rather than treated as secondary measures.

Second, **installed capacity alone is not an adequate measure of energy security**. Utilization, dispatch, fixed and capacity-payment dilution, transmission constraints, hydrological conditions, curtailment and demand structure materially influence the amount and economic value of useful energy delivered by the system.

Third, **indigenous-resource security depends on commercial deliverability rather than resource or discovery counts alone**. Oil and gas exploration, appraisal and brownfield redevelopment remain important, but continued drilling and reserve additions must ultimately translate into sustained commercial production if they are to reduce import and foreign-exchange exposure. The same principle applies to geothermal and other technically identified resources: resource indication is not equivalent to a bankable energy project.

These findings support a portfolio interpretation of energy security in which continued hydrocarbon exploration and productivity improvement, diversified indigenous generation, transmission and storage, water-aware resource development, existing-asset utilization and demand-side efficiency contribute complementary functions.

38.3 Remaining evidence limits

The most important unresolved system-level limitation is the absence of a fully assembled and independently quality-controlled **current 8,760-hour dataset** containing national and regional demand or net load, unit-level dispatch and

outages, hydro inflow and reservoir chronology, fuel constraints, distributed-generation chronology and nodal or corridor transmission limits.

This limitation restricts the precision with which the study can estimate chronological adequacy, curtailment, storage duration and cycling, hydro dispatch, congestion, reserve requirements and an optimized 2040 or 2050 generation mix. It does not invalidate the annual, resource, project, operating-economic or comparative evidence developed elsewhere in the synthesis.

Accordingly, the 2030-2050 pathways remain **transparent screening scenarios rather than forecasts or a uniquely demonstrated national least-cost optimum**. A future chronological production-cost, reliability and transmission-constrained model should be undertaken when the required primary datasets can be assembled on a consistent basis.

Table 38.1: Integrated evidence status, permitted interpretation and remaining decision gates.

Component	Status in final manuscript	Final treatment
National energy baseline	Strong current annual and partial-year official evidence	Use current national and regional evidence for system structure and trends; retain period and reporting-boundary cautions where definitions differ.
Resource and technology evidence	Strong but technology- and location-dependent	Use for resource suitability and comparative screening; require site- and project-specific validation before stronger development conclusions.
Existing plant and portfolio economics	Ready for observed / point-forward screening	Use operating-cost, utilization and remaining-life evidence where current inputs are available; keep missing O&M, tariff, dispatch and financing inputs explicit.
Full project DCF and bankability	Mixed; decision-grade only for limited cases	Use full DCF only where the evidence gate is satisfied. Retain incomplete project runs as screening or historical reconstruction, not investment conclusions.
International comparator evidence	Ready for functional comparison	Use comparator countries to identify transferable mechanisms and enabling conditions; do not copy national fuel shares or treat comparator costs as observed Pakistan costs.
Regional Pakistan portfolios	Ready as differentiated screening framework	Use regional resource, water, grid and demand differences to frame options; do not present regional allocations as optimized capacity targets.
2030-2050 pathways	Scenario-grade only	Retain multiple transparent pathways and sensitivity cases; do not claim a uniquely proven least-cost national optimum.
Primary current 8,760-hour optimization	Not yet decision-grade	Complete demand, unit dispatch/outages, hydro chronology, distributed generation and nodal-transfer data are still required before chronological system optimization.

38.4 Economic and bankability evidence boundary

The economic analysis deliberately distinguishes **historical/full-life investment reconstruction, point-forward existing-asset economics, sourced proposed-project economics, comparator-derived prospective scenarios and illustrative screening cases**.

Brill-Viz provides a common analytical structure for cash flow, NPV, IRR, LCOE or LCOS, debt-service coverage, sensitivity and uncertainty analysis, but the strength of any result remains conditional on the strength of its inputs. In the present validation set, Safe Solar provides the strongest Full-DCF evidence case. Dawood, Karot, Bhikki and other representative projects provide useful historical reconstruction or screening information where current O&M, financing, tariff, dispatch or resource inputs remain incomplete. Geothermal, C-5 nuclear, battery-storage and hybrid cases remain explicitly conditional on resource, financing, project-cost or system-value evidence that has not yet been fully established.

Calculated outputs from incomplete cases are therefore retained for analytical transparency but are not promoted to investment-grade conclusions. The purpose of the evidence gate is to identify precisely which additional information would permit a stronger economic interpretation.

38.5 Decision framework and next evidence tests

The synthesis therefore supports **conditional decision analysis rather than a universal technology ranking**. A stronger project or policy conclusion requires progression through a consistent evidence chain: physical resource confirmation; complete and current project cost; realistic financing; credible utilization or dispatch; grid and water compatibility; system value; investor bankability; consumer affordability; and uncertainty testing.

International comparator evidence enters this chain as a source of mechanisms and enabling conditions rather than as proof that an outcome achieved elsewhere will automatically occur in Pakistan. Likewise, global technology-cost benchmarks provide prospective screening inputs, not Pakistan project quotations.

The next evidence tests should therefore concentrate on those inputs most capable of changing decisions: complete hourly operating chronology, current project CAPEX and O&M, financing terms, plant-level dispatch and fuel consumption, hydro and transmission chronology, geothermal reservoir and drilling evidence, storage service revenues, site-specific water requirements and field-level hydrocarbon reserve-development performance.

38.6 Role of the synthesis as a master evidence framework

This synthesis serves as the **master evidence document** for the research programme. It retains the full chain connecting resource evidence, technology performance, water, transmission, operating utilization, project economics, financing, uncertainty and system value across geothermal, hydropower, solar, wind, coal, oil and RFO, natural gas and RLNG, nuclear energy, bioenergy, waste, storage, transmission, efficiency and demand-side measures.

The accompanying Policy Options paper draws selectively from this larger evidence base for decision-facing use, but the analytical boundary remains the same: observed evidence, published interpretations, derived calculations, scenario results and integrated conclusions remain distinguishable and traceable.

The framework is consequently intended to remain updateable. New Energy Yearbooks, regulatory decisions, operating records, petroleum discoveries and development results, resource measurements, project-finance evidence and chronological system data can be incorporated without requiring the underlying analytical principles to change. The objective is not to preserve a fixed future energy mix, but to provide a transparent framework through which Pakistan's energy options can be reassessed as the evidence itself changes.

PART XI – CONCLUSIONS, STRATEGIC DIRECTIONS AND FUTURE EVIDENCE

39. Conclusions, Comparative Lessons and Strategic Directions

39.1 What this synthesis set out to determine

This study was undertaken to examine whether Pakistan can improve energy security, affordability and economic resilience by making more productive use of indigenous resources and existing infrastructure while reducing avoidable dependence on imported energy. It deliberately moved beyond the proposition that energy security can be achieved by adding generating capacity or by identifying one technology as a national “game changer”.

The evidence instead treats energy security as a system property determined by resource availability, commercial deliverability, utilization, fuel and foreign-exchange exposure, transmission capability, hydrology and water availability, demand structure, financing, reliability and consumer affordability.

The international comparison was fundamental to this approach. It was not intended to identify a country whose energy mix Pakistan should reproduce. It was used to identify **proven functions, institutional arrangements and technical practices** that can be tested against Pakistan's own geology, resources, infrastructure and economics.

39.2 What the international comparison contributes

The comparison shows that successful energy systems are rarely the product of one resource alone. They are the result of matching domestic resource endowment with technology, infrastructure, financing and system design.

India demonstrates how a large South Asian system can combine substantial indigenous thermal resources with hydropower and rapidly expanding renewable capacity while facing continuing growth and infrastructure demands. China demonstrates the role of scale, domestic industrial capability, transmission and coordinated technology deployment. The United States demonstrates how technological innovation can transform an indigenous resource into a commercially important source of supply and alter the national fuel balance.

The more specialized comparator countries provide additional lessons: geothermal resources become investable only after exploration risk is managed; variable renewables require flexibility and grid architecture; hydropower value depends on chronology and reservoir management rather than annual energy alone; and lower-temperature geothermal resources can have economic value through direct heat without necessarily producing electricity.

The principal lesson from the comparison is therefore **adaptation rather than imitation**. Pakistan benefits from international experience when the underlying mechanism is identified and then tested under Pakistan-specific geological, financial, grid, water and institutional conditions.

39.3 What the evidence establishes about Pakistan

The evidence assembled in this synthesis indicates that Pakistan's energy vulnerability increasingly reflects the gap between domestic resource delivery and demand rather than simply a shortage of installed electricity capacity.

Domestic oil and gas production has weakened while imported fuels continue to expose the economy to foreign-exchange requirements and international price and supply shocks. Exploration activity and discoveries remain essential, but discovery counts cannot substitute for commercially deliverable reserve replacement. Chapter 38 already reaches this distinction explicitly.

At the same time, significant losses, under-utilization, capacity-payment dilution and transmission constraints demonstrate that new supply is not the only way to increase usable energy. Energy that is presently lost, curtailed, inefficiently dispatched or consumed unnecessarily represents an economic resource that can be compared against additional generation.

The resulting energy-security question is therefore broader:

How can Pakistan obtain the greatest reliable and affordable energy service from every unit of domestic fuel, water, infrastructure and capital while retaining enough diversification to withstand resource decline, hydrological variability, import shocks and technological change?

39.4 Oil and gas: replacement remains important, but future security cannot depend on discoveries that have not yet occurred

Continued exploration, appraisal, brownfield redevelopment and enhanced recovery remain important because indigenous oil and gas retain substantial economic and strategic value. Pakistan also possesses decades of geological, seismic, drilling, petrophysical and reservoir expertise that can continue to contribute to exploration and potentially to geothermal development.

However, energy planning cannot assume that future discoveries will necessarily replace production at the rate or timing required by national demand. The evidence therefore supports a dual interpretation.

One track is continued pursuit of commercially viable hydrocarbon reserve replacement and improved recovery from existing fields.

The second is reduction of unnecessary consumption of scarce domestic hydrocarbons where the same energy service can be delivered more efficiently by another indigenous resource or through efficiency.

Under this interpretation, renewable energy, hydropower, nuclear generation, efficiency and other technologies do not replace the need for exploration. They can instead **extend the economic life and strategic value of finite domestic hydrocarbons** by reducing their use where substitutes are technically and economically superior.

39.5 What “sustainable energy systems” means in this study

Sustainability in this synthesis does not mean maximizing the share of one category labelled renewable or low-carbon. It means maintaining energy services over time without creating unacceptable dependence on finite resources, imported fuels, water, infrastructure capacity, unaffordable finance or environmental burdens.

A technically sustainable energy system therefore requires simultaneous attention to resource replenishment or renewability, affordability, reliability, water, infrastructure, financing and environmental constraints.

This leads to a portfolio interpretation.

Solar and wind provide potentially low-operating-cost indigenous energy where resource quality and transmission permit useful delivery. Hydropower provides energy and flexibility but remains subject to hydrology, reservoir operations and water competition. Nuclear power can provide high-utilization firm generation where financing, construction, water and system conditions are manageable. Domestic thermal resources can contribute security and flexibility where their complete delivered-system economics justify their use. Bioenergy can add value where sustainable feedstock and cogeneration economics exist. Geothermal remains a potentially important indigenous resource but requires direct subsurface validation before large-scale commercial claims are justified. Storage and demand response derive value from the services they provide to the system rather than simply from installed capacity.

No one of these resources performs every system function.

39.6 What “energy security” means in this study

Energy security therefore cannot be measured only by installed megawatts or by domestic fuel share. A secure system is one that can continue delivering essential energy services under changing demand, domestic production decline, dry hydrological years, fuel-price shocks, foreign-exchange constraints, equipment outages and transmission limitations without imposing unsustainable costs on consumers or investors.

This interpretation makes diversification valuable not because diversification is inherently desirable, but because different resources fail under different conditions.

Solar and wind are exposed to chronology and grid availability. Hydro is exposed to hydrology. Imported thermal generation is exposed to fuel and foreign exchange. Domestic fossil resources are finite and subject to depletion. Nuclear is capital-intensive and long-lived. Geothermal contains upstream resource uncertainty. Storage does not create primary energy and requires a viable service stack. The security value lies in combining these characteristics intelligently rather than maximizing any single technology.

39.7 What the Brill-Viz economics adds

The economics undertaken through Brill-Viz provides a second discipline to the resource comparison. A technically attractive resource does not automatically become an investable or affordable project.

The study therefore separates full-life investment economics from point-forward economics and distinguishes historical project evidence from present operating conditions. Unsupported inputs remain gated rather than being replaced with

generic assumptions. Chapter 38 records that only the strongest evidence case presently reaches a complete Full-DCF gate, while several other cases remain screening, reconstruction or system-value cases.

This is an important result rather than a limitation to conceal. It identifies exactly where better evidence is required before technology comparisons can become investment-grade.

The next stage of economic research is therefore not simply to run more calculations. It is to improve the quality of the inputs that determine those calculations.

39.8 Strategic directions emerging from the evidence

Taken together, the evidence describes an energy-security framework with several mutually reinforcing characteristics.

Existing generation and network assets are evaluated for better utilization before equivalent new capacity is assumed to be necessary. Economically avoidable network losses and curtailment are treated as recoverable energy resources. Domestic oil and gas exploration and production enhancement continue alongside diversification that reduces unnecessary depletion of those resources. Variable renewable development is coupled to transmission, flexibility and demand chronology rather than evaluated through plant LCOE alone. Hydropower, nuclear and potentially validated geothermal resources provide firm or flexible complements where their specific constraints are acceptable. Storage is valued according to congestion relief, ancillary services, renewable integration and avoided network or generation investment. Efficiency and demand response compete directly with supply investment where they can provide the same energy service at lower system cost.

The international evidence does not establish technology quotas for Pakistan. It identifies the conditions under which technologies and institutions have worked elsewhere. The Pakistan analysis then determines whether those conditions exist locally or what would be required to create them.

39.9 Regional differentiation is fundamental

A national energy strategy does not require every province or resource region to adopt the same portfolio.

Punjab, Sindh, Balochistan, KP, Gilgit-Baltistan and AJK differ materially in resource quality, demand density, hydrology, water availability, existing infrastructure and transmission access. The manuscript therefore already treats regionalization as a fundamental analytical requirement rather than a secondary implementation issue.

The national system can be understood as the integration of these regional strengths and constraints. Resource development therefore gains value when it is considered simultaneously with where demand occurs and how the energy will be transported, stored or consumed.

39.10 Final conclusion

The strongest conclusion of this synthesis is that Pakistan's long-term energy security depends less on identifying a single new resource than on **using all available resources more intelligently**.

The underlying national objective can be expressed simply:

Increase useful, reliable and affordable energy delivered per unit of domestic resource, imported fuel, water and invested capital, while continuously increasing the share that can be supplied from commercially sustainable indigenous sources.

This requires continued exploration for replacement oil and gas reserves, but it also requires conservation of those resources through efficiency and substitution where economically justified. It requires development of renewable and firm indigenous resources, but also the networks and flexibility needed to make them useful. It requires investment, but investment must remain affordable to the system and consumer.

The synthesis therefore does not identify an endpoint energy mix. It establishes an evidence-based method for continually moving toward greater resilience, greater resource productivity and greater indigenous self-reliance as better data, technologies and resource discoveries become available.

40. Research Agenda, Data Priorities and Next-Generation Economics

40.1 Why the present synthesis is a foundation rather than an endpoint

The present study closes many of the highest-value evidence gaps that can be addressed from publicly available information. It establishes a current national baseline, integrates energy and water evidence, compares principal resource families, introduces regional and international comparator frameworks, develops project-economic screening and documents the boundaries beyond which the evidence does not presently justify more precise conclusions.

The largest remaining limitations are not conceptual. They are **data-resolution limitations**.

The manuscript correctly identifies the most important unresolved issue as the lack of an independently assembled current 8,760-hour dataset containing demand, unit dispatch, outages, hydro chronology and nodal transmission limits.

Consequently, the 2040 and 2050 pathways remain screening scenarios rather than a uniquely proven optimal mix.

40.2 Priority evidence required for the next research generation

The next stage would benefit most from an integrated dataset covering:

Table 40.1. Evidences required for next research generation

Evidence required	Research value
Hourly national and regional demand/net load	Chronological adequacy, flexibility and storage modelling
Unit-level generation, dispatch, availability and outages	Actual operating economics and capacity value
Reservoir inflow, storage and dispatch chronology	Firm hydropower and dry-year economics
Nodal transmission limits, losses and congestion	Locational generation/storage value
Distributed and net-metered solar production chronology	Reconciliation of grid demand and behind-the-meter generation
Plant/project CAPEX, O&M, financing and tariff architecture	Upgrade from screening to full DCF
Fuel, freight, levy and FX exposure by plant	Point-forward thermal economics
Technology- and site-specific water withdrawal/consumption	Water-energy optimization
Field-level petroleum reserves, revisions, production and commercial discoveries	Reserve-replacement and depletion assessment
Geothermal temperature, gradient, permeability, flow, injectivity and chemistry	Conversion of prospectivity into resource/reserve economics
Demand-side marginal efficiency cost curves	Direct comparison with new generation
Storage service revenue and avoided-system-cost data	Bankable BESS and pumped-storage economics

40.3 From screening economics to decision-grade economics

The present Brill-Viz work provides a structured foundation because it records missing evidence rather than concealing it. A future full economic evaluation for each major project or representative technology would ideally include a defensible construction schedule, development and EPC CAPEX, O&M, financing structure, tax, tariff or revenue mechanism, fuel or feedstock, capacity and degradation, water requirements, grid/interconnection cost, major replacements and decommissioning.

When these inputs become available, the existing framework can progressively upgrade representative cases from screening to complete project DCF without changing the economics engine itself.

That is an important feature of the methodology: **better evidence improves the answer without requiring a different analytical philosophy.**

40.4 Future international comparison

The comparator programme should also remain dynamic. Future work can deepen the India comparison because of geographic proximity, Himalayan hydrology, large-scale coal use, rapid renewable expansion and comparable development pressures. China remains relevant for transmission, industrial supply chains and deployment at scale. The United States remains useful for resource-development technology and the impact of innovation on the fuel mix.

Additional countries should be introduced only where they answer a defined Pakistan question.

This avoids turning comparative research into a catalogue of national energy shares. The purpose remains to identify practices and mechanisms that can be translated into measurable Pakistan variables.

40.5 A living evidence system

The companion database and Brill-Viz workflow allow this synthesis to function as a **living evidence document**. New Energy Yearbooks, Economic Surveys, regulatory determinations, project costs, field discoveries, reserve revisions, generation records, hydrological observations and transmission data can be incorporated while retaining their dates, evidence classes and original definitions.

The analytical conclusions can then be re-tested instead of rewritten from scratch.

This is especially valuable for petroleum exploration. A material new oil or gas discovery should change the resource outlook only when reserves, deliverability, development timing and economics become sufficiently established. Similarly, a geothermal prospect should move from geological prospectivity to commercial planning only after temperature, productivity, injectivity and economic evidence justify that transition.

40.6 Research objective for the next version

The eventual next-generation objective should be a linked model comprising: **resource evidence - project economics - chronological dispatch - transmission constraints - water constraints - import/FX exposure - consumer/system affordability.**

Such a model would allow the Investor-Consumer Bankability Window to move from a research prototype toward a more complete system-planning tool.

It would also allow the question that motivated this synthesis to be answered more rigorously; not simply **which energy source is cheaper**, but **which combination of domestic resources, imported fuels, infrastructure, efficiency and investment can deliver the required energy service at the lowest defensible economic and security cost under Pakistan's actual operating constraints?**

40.7 Closing research perspective

The present Synthesis should therefore be treated neither as a final prediction nor as a temporary literature review. Its value lies in creating a traceable national evidence framework that can evolve as Pakistan discovers new resources, develops new infrastructure, changes its demand profile and gains better operating data.

Until those additional datasets become available, its principal role is to distinguish:

- what is already supported by evidence,
- what is economically screenable,
- what remains prospective, and
- what information is still required before major conclusions become decision-grade.

41. Data Availability and Reproducibility

This study is a synthesis of publicly available and project-held secondary data; no new primary field, laboratory or market-survey data were generated specifically for this work. The evidence base integrates official Pakistani energy, power-sector, petroleum, water and infrastructure statistics; publicly available project and tariff records; international technology and cost benchmarks; published geological and geochemical information; and selected project-finance and operational datasets cited throughout the manuscript.

To preserve analytical transparency, the study distinguishes three principal evidence classes: **reported observations**, **derived calculations**, and **scenario or screening results**. Published plant capacities, generation, fuel use, tariffs, reserves, production, drilling activity, water availability and other source values are retained separately from values calculated by the author. Forward-looking energy-mix, geothermal, storage, transmission and economic scenarios are identified explicitly as analytical screening cases rather than reported observations.

Companion project-held workbooks provide the structured data used for the manuscript figures, energy-system comparisons and economic evaluations. The current manuscript chart dataset contains the source-controlled plotting data and generic chart keys used to reproduce the analytical figures, while dedicated economics workbooks preserve the distinction between **full-life/investment evaluation** and **point-forward/remaining-life evaluation**. Brill-Viz was used to generate and review selected descriptive statistics, visualizations, project-economics outputs, sensitivity analyses, Monte Carlo simulations and interpretive summaries. Where an economic case lacked sufficiently defensible CAPEX, tariff/revenue, operating-cost, financing, resource or performance evidence, the analysis was deliberately gated rather than completed using unsupported default assumptions.

The Pakistan Energy Yearbook 2024-25 provides the principal current national energy baseline, supplemented by NEPRA, PPIB, Planning Commission, WAPDA and other cited Pakistani and international sources. Original source definitions, reporting periods and units are retained wherever practicable. Derived figures may contain minor differences caused by rounding in the published source tables and are identified accordingly.

The study does not claim to reproduce a complete national least-cost power-system optimization. A fully integrated current dataset containing hourly demand, unit-level dispatch, hydrology, fuel constraints, nodal transmission limits, outages and other required 8,760-hour system variables was not publicly available in a sufficiently complete form. Consequently, the 2030–2050 pathways are presented as **transparent comparative screening scenarios**, intended to support further modelling rather than substitute for detailed system-operator or investment-grade optimization.

Redistribution of third-party source material remains subject to the copyright, licensing and acknowledgement requirements of the respective publishers. The manuscript therefore provides source attribution and sufficient methodological description to reproduce the analytical approach while avoiding republication of restricted source material where permission has not been established.

42. Declarations

Funding. This research received no external research grant, institutional sponsorship or commissioned funding. The study was conceived, developed and undertaken independently by the author.

Conflict of interest. The author is the founder of enerbrill and the developer of Brill-Viz, the analytical and visualization platform used for portions of the data analysis, project-economics evaluation, visualization and interpretive workflow in this study. Brill-Viz and related applications may have present or future commercial value. This relationship is disclosed as a potential commercial interest. No external commercial organization, technology vendor, project developer, fuel supplier, financial institution or government entity influenced the research questions, data selection, analytical treatment, interpretation or conclusions of the study. The author declares no other competing interests.

Author contributions. Khan Arshad is solely responsible for the conceptualization and design of the study; definition of its research questions and analytical framework; literature and data review; compilation, quality control and integration of energy, petroleum, geological, geochemical, water, infrastructure and economic evidence; development of

comparative and scenario analyses; project-economics screening; visualization; interpretation; development and application of the Brill-Viz analytical workflow; preparation of figures and supporting datasets; manuscript drafting; and subsequent revision and integration of the study.

Use of analytical software and AI-assisted tools. Brill-Viz was used as an author-developed analytical, visualization and project-economics platform. Where AI-assisted research or document-analysis tools were used to support literature organization, drafting, data review or presentation, their outputs were treated as assistance rather than primary evidence. Source selection, quantitative inputs, interpretation, methodological decisions and final conclusions remained under the author's responsibility.

About the Author



Khan Arshad is a petroleum geologist, exploration professional and independent energy-data researcher with nearly three decades of experience in oil and gas exploration, regional geological studies, petroleum-system analysis, prospect evaluation, petroleum economics and exploration project management. He holds an M.Sc. in Petroleum Geology from the University of Aberdeen, United Kingdom, and an M.Sc. in Geology from the University of Karachi, Pakistan.

His professional career has included technical and managerial assignments in Pakistan with Baker Hughes INTEQ, OMV, PETRONAS, MND, Eni and Dewan Petroleum. His experience spans wellsite and operations geology, seismic and petrophysical interpretation, sequence stratigraphy, regional basin analysis, new ventures, prospect generation, exploration-risk and reserves assessment, exploration-team leadership and major exploration-project management.

A substantial part of his professional work has focused on the geological and petroleum-system evaluation of Pakistan's sedimentary basins, including the Middle and Lower Indus basins, Kirthar and Sulaiman fold belts, Potwar Basin and Punjab Platform. His work has involved regional fairway analysis, source-reservoir-seal evaluation, conventional and unconventional resource assessment, exploration portfolio development and integration of geological, geophysical, petrophysical and geochemical evidence.

He is currently self-employed as the founder of **enerbrill**, where he combines petroleum exploration experience with data analytics, scientific visualization and software development. He has independently developed **Brill-Viz**, an integrated analytical and visualization platform, together with specialized applications for probabilistic volumetrics, geological chance-of-success assessment, petrophysical evaluation, Total Organic Carbon estimation, decision analysis, mind mapping, research synthesis and AI-assisted document intelligence.

The present study extends that multidisciplinary experience beyond conventional petroleum exploration into the broader question of **Pakistan's long-term energy security**. It integrates petroleum-resource decline and replacement, indigenous and imported fuels, renewable and firm generation technologies, geothermal opportunity, hydropower, nuclear energy, bioenergy, storage, transmission, water constraints, project economics, efficiency and consumer affordability within a common analytical framework. Its purpose is to provide an independent, evidence-based synthesis that can support researchers, policymakers, investors and energy-sector professionals in distinguishing technically attractive opportunities from those that remain constrained by resource, infrastructure, financing or evidence limitations.

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Appendix A - Companion Evidence Database Architecture

The companion workbook is a cumulative evidence architecture rather than a manuscript chapter sequence. The worksheet identifiers below run continuously from 00 to 121; all sheets are listed so that manuscript references can be traced directly to the database without relying on development-version labels **(This database is, however, not shared along with the synthesis and is only kept for author's personal use)**.

Core register and baseline sheets (00-19)

- 00_ReadMe: workbook scope, evidence classes, update rules and interpretation cautions.
- 01_Source_Register: master source register with Source_ID, publisher, date, evidence class, links and use cautions.
- 02_PK_Power_Baseline: Pakistan installed-capacity and electricity-generation baseline used for national system comparisons.
- 03_PK_Electricity_EndUse: sectoral electricity-consumption evidence for household, commercial, industrial, agricultural and other demand.
- 04_PK_RE_Capacity_Trend: standardized IRENA renewable-capacity series used for Pakistan solar, wind and hydropower trends.
- 05_PK_Petroleum_Imports: petroleum/crude import quantities and values used for import-exposure analysis.
- 06_PK_Gas_Consumption: indigenous-gas and RLNG consumption by sector for the current Pakistan baseline.
- 07_PK_Coal_Consumption: reported coal consumption by sector and supporting indigenous/imported-coal context.
- 08_PK_Water_Baseline: national and regional water-resource, withdrawal and stress indicators relevant to energy planning.
- 09_Global_RE_Costs_2024: IRENA global renewable installed-cost, capacity-factor and LCOE benchmarks for 2024 projects.
- 10_Global_Geothermal: global geothermal capacity, cost, utilization and comparator evidence.
- 11_PK_Geo_HotSprings: Pakistan geothermal-manifestation temperatures and geochemical observations.
- 12_PK_Geo_HeatFlow: Zindapir geothermal-gradient and heat-flow evidence from published magnetic analysis.
- 13_PK_Geo_Reservoirs: published formation/reservoir temperature and property evidence for Pakistan geothermal screening.
- 14_PK_VRE_WB_Scenario: World Bank/ESMAP variable-renewable planning evidence and locational scenario inputs.
- 15_Economics_Input_Register: required project-economics inputs, evidence status and missing-data fields.
- 16_Research_Hypotheses: testable study hypotheses, current status and discriminating evidence.
- 17_Chart_Register: figure/chart definitions, source sheets and intended analytical use.
- 18_Evidence_Gaps: evidence-gap register, priorities and required next data acquisitions.
- 19_Master_Long_Data: normalized long-form master evidence table for reproducible analysis and charting.

Resource, economics, regional and scenario sheets (20-61)

- 20_PK_Geo_Prospect_Inventory: published Pakistan geothermal manifestation and temperature-screening inventory.
- 21_PK_Project_Economics: representative public project cost, tariff, energy and financing evidence.
- 22_SafeSolar_Cost_Breakdown: detailed tariff-petition cost architecture used as a project-economics evidence case.
- 23_Geothermal_Econ_Risk: global geothermal cost/performance benchmarks and Türkiye exploration-risk financing analogue.
- 24_Economics_Model_Staging: source-controlled economics input matrix; unsupported project inputs remain blank.
- 25_PK_Hydro_Resources: PPIB regional identified hydropower potential, installed capacity and derived developed share.
- 26_PK_Hydro_Project_Portfolio: operating, under-construction and ready-for-construction hydro projects with capacity, energy, storage and source links.

- 27_PK_Hydro_2025_Actual: calendar-year 2025 WAPDA hydel generation by major station/group.
- 28_PK_Pumped_Storage: official pumped-storage planning evidence plus requirements for bankable site screening.
- 29_PK_Solar_Measurements: public Pakistan solar-station measurement network and source metadata.
- 30_PK_Solar_Resource: solar-resource atlas layers and published regional resource indicators.
- 31_PK_Wind_Measurements: public wind-mast measurement network and source metadata.
- 32_PK_Wind_Resource: wind-resource atlas layers and published regional resource indicators.
- 33_PK_VRE_Grid_Integration: World Bank planning/model evidence and current BEST-PAK grid-integration quantities.
- 34_Balochistan_Hybrid_Cases: explicitly modelled solar-wind-HVDC cases; scenario evidence rather than observed tariffs.
- 35_PK_Hydro_Finance: public Gulpur, Dasu, Tarbela and WAPDA fleet finance/performance evidence.
- 36_Common_Econ_Cases: common technology/project cases with evidence class, original units, derived capital intensity and model-readiness status.
- 37_PK_Thermal_Coal_Cases: PPIB project evidence for Bhikki, Haveli Bahadur Shah, PTPL/Trimmu and Engro Thar.
- 38_PK_Nuclear_2024_C5: PAEC unit performance plus Planning Commission C-5 PC-I investment evidence and source-QA discrepancy.
- 39_NEPRA_System_Cost_FY25: FY2024-25 power-purchase cost, CPP/EPP split, per-kWh components and utilization evidence.
- 40_Econ_Readiness_Matrix: explicit completeness test for inputs required by cross-technology DCF/economic modelling.
- 41_BrillViz_Econ_Export: long-form source-controlled economics inputs prepared for Brill-Viz Economics.
- 42_Normalization_Rules: rules for currency, price-year, tariff, capacity, generation, storage, hydro, geothermal and nuclear comparability.
- 43_Regional_Summary: compact regional hydro, VRE, water, grid-proxy and screening-portfolio baseline.
- 44_Regional_Water: provincial water resource/use evidence with explicit gaps for GB and AJK.
- 45_Regional_Grid_Proxies: NEPRA DISCO loss, recovery and reliability evidence with regional proxy summaries.
- 46_Regional_Resource_Evidence: region-technology evidence combining hydro, VRE, nuclear, coal/gas, bioenergy and geothermal screening.
- 47_Regional_Priority_Matrix: transparent 0-4 integrated screening scores and portfolio roles; not published measurements.
- 48_Regional_Action_Roadmap: sequenced regional and interregional actions with principal constraints and Source_IDs.
- 49_Regional_Chart_Data: chart definitions and evidence-status cautions for regional figure generation.
- 50_BrillViz_Regional_Export: long-form regional screening metrics for direct Brill-Viz use.
- 51_Published_Scenario_Anchors: current IGCEP/ISP demand cases plus published 2040/2047 external or legacy comparators kept by evidence type.
- 52_IGCEP_2035_Reference: approved/reference 2035 installed-capacity mix with clean and renewable/hydro flags.
- 53_Scenario_Tech_Assumptions: explicit capacity-factor and partial CAPEX proxies used only for post-2035 screening conversions.
- 54_Scenario_Definitions: editable scenario pathway definitions and post-2035 demand, load-factor and flexibility assumptions.
- 55_Scenario_Generation_Shares: transparent 2040/2050 generation-share assumptions with 100% checks.
- 56_Scenario_Outputs: derived demand, peak, clean/VRE/import shares and storage/flexibility stress-test quantities.
- 57_Indicative_Capacity: energy-equivalent technology capacity conversion; not a reserve-margin or unit-commitment plan.
- 58_Capital_Envelope_Proxy: partial capital-intensity screening only where sourced proxies exist; unsupported technologies remain blank.
- 59_Scenario_Summary: compact 2040/2050 pathway comparison used by Brill-Viz and manuscript figures.

- 60_Integrated_Roadmap: phased 2026-2050 actions and evidence decision gates before major capital commitments.
- 61_Scenario_Dashboard: visual scenario dashboard separating published planning anchors from study screening extensions.

System integration, comparator and bankability sheets (62-69)

- 62_Chronological_Evidence: published Pakistan load, demand, dispatch and reserve/flexibility evidence plus derived diagnostics.
- 63_Chronological_Model_Readiness: readiness scoring and explicit data gates for a current 8,760-hour model.
- 64_Global_Comparators: function-specific international evidence for selected comparator countries.
- 65_Comparator_Transferability: transparent Pakistan transferability screening across resource, grid, finance, water/heat and institutional dimensions.
- 66_Bankability_Screening: prototype affordability comparison against the FY2024-25 average power-purchase-cost proxy using dated FX.
- 67_Investor_Consumer_Window: formal investor-floor / consumer-system-ceiling framework and required evidence.
- 68_System_Findings: evidence status of the principal system-integration conclusions.
- 69_System_Dashboard: compact chronology, dispatch, comparator and affordability dashboard.

Chronology and project-finance sheets (70-83)

- 70_FY25_Monthly_Load: FY2024-25 monthly true peak, average and minimum demand with evidence-status flags.
- 71_Selected_Hourly_Profiles: selected monthly-average H00-H23 load points for summer/spring net-load screening.
- 72_Seasonal_Ramps: seasonal peak, trough and ramp metrics derived from the available chronology.
- 73_Demand_Response_Cases: sector-decomposition and commercial-closing peak-reduction cases.
- 74_BESS_Value_Proxy: energy-only storage-value screening from published marginal-cost evidence and an explicit round-trip-efficiency benchmark.
- 75_SafeSolar_DCF_Assumptions: source-controlled assumptions for the Safe Solar prototype DCF.
- 76_SafeSolar_DCF: annual Safe Solar project/equity cash-flow calculations and prototype bankability outputs.
- 77_SafeSolar_Sensitivity: one-way sensitivity cases for key Safe Solar DCF assumptions.
- 78_SafeSolar_MonteCarlo: seeded Monte Carlo uncertainty results for the Safe Solar prototype.
- 79_Bankability_Window_Cases: prototype investor-floor/system-ceiling comparisons with period, currency and evidence cautions.
- 80_Chronology_Findings: integrated chronological-system findings and evidence status.
- 81_Full8760_Model_Gate: explicit primary-data gates before a genuine current production-cost/reliability model.
- 82_BrillViz_Chronology_Export: long-format chronology and bankability outputs prepared for Brill-Viz.
- 83_Chronology_Dashboard: visual chronology and project-bankability dashboard.

Current-system and tariff-calibration sheets (84-97)

- 84_Current_Data_Status: closure status for primary chronological, grid, tariff and economics inputs.
- 85_TSEP_Grid_Calibration: TSEP 2025-35 delays, renewable induction, network-cost categories, KE-transfer changes and KAPCO-area reinforcement evidence.
- 86_CY2026_System_Cost: current NEPRA energy, capacity, UoSC and total power-purchase-price forecast with reconciliation checks.
- 87_QASPL_Current_Tariff: 2026 QASPL tariff/indexation components and current screening basis.
- 88_Karot_Current_Tariff: 2026 Karot tariff/indexation components and equivalent screening basis.
- 89_Bhikki_Current_Tariff: 2026 Bhikki RLNG tariff, fuel, O&M and utilization-sensitive screening components.
- 90_MultiTech_2026_Normalized: common-year multi-technology screening against current system-cost evidence.
- 91_Bankability_Window_2026: strengthened current-year Investor-Consumer Bankability Window screening.

- 92_Locational_Value_Framework: energy, capacity, transmission, voltage, reserve, fuel/FX and water layers for project-specific system value.
- 93_Resource_Ch12_14_Status: evidence-readiness matrix for Coal/Oil/Gas, Nuclear and Bioenergy/Waste chapters.
- 94_Current_Calibration_Findings: integrated findings from the current-system calibration.
- 95_FullModel_Gates: remaining data/model gates before decision-grade chronological and locational analysis.
- 96_BrillViz_Current_Export: long-form current-system calibration outputs for Brill-Viz.
- 97_Current_System_Dashboard: current-system tariff, grid and bankability dashboard.

Realized-performance and evidence-closure sheets (98-112)

- 98_Data_Closure: closure status for chronological, coal, nuclear, bioenergy, storage and realized-performance evidence blocks.
- 99_FY25_Realized_Plant_Costs: plant-level FY2024-25 generation, utilization, CPP, EPP, PLAC and derived procurement-cost proxies.
- 100_Coal_Local_vs_Imported: same-year local-Thar versus imported-coal utilization and procurement-cost comparison.
- 101_Thar_Coal_Current_Fuel: current Thar-coal fuel/indexation context.
- 102_Nuclear_FY25_Performance: unit-level nuclear utilization, generation and observed annual procurement-cost proxies.
- 103_C5_Finance_Water: C-5 PC-I investment/financing evidence and Chashma cooling-water interface.
- 104_Bioenergy_FY25_Performance: FY2024-25 bagasse project utilization and operating-performance evidence.
- 105_Bioenergy_Project_Econ: representative PPIB bagasse project-cost and capital-structure evidence.
- 106_ADB_BESS_Project: Pakistan-specific proposed transmission-level BESS scale, services and financing envelope.
- 107_Realized_vs_Proxy: observed annual Bhikki/Karot performance compared with earlier screening proxies.
- 108_Ch12_14_Closure: evidence closure linking resource Chapters 12-14 with realized operating/project data.
- 109_Integrated_Findings: cross-domain integrated findings retained for final synthesis.
- 110_Finalization_Gates: publication-readiness and unresolved-evidence gates.
- 111_BrillViz_Final_Export: source-controlled long-form final outputs for Brill-Viz.
- 112_Final_Dashboard: final evidence/status dashboard.

Source-integration, probabilistic economics and manuscript-chart sheets (113-121)

- 113_GoP_Outlook_2021_30: Pakistan Energy Outlook 2021-2030 data retained as a historical official planning/forecast benchmark.
- 114_GoP_YearBook_2023_24: Power Division Year Book 2023-24 administrative, policy and implementation checkpoint.
- 115_GoP_Budget_2025_26: Power Division/NEECA FY2025-26 institutional budget evidence, kept separate from project CAPEX.
- 116_BrillViz_Econ_Master: direct Brill-Viz economics input schema for representative energy-project cases and audit metadata.
- 117_Prob_Econ_Distributions: probabilistic uncertainty ranges, Monte Carlo controls and optional macro/geopolitical stress overlays.
- 118_Prob_Econ_Summary: standardized P10/P50/Mean/P90 probabilistic-economics output summary and rerun queue.
- 119_Econ_Engine_Map: mapping from evidence-database fields to Brill-Viz economics engine keys and units.
- 120_BrillViz_Manuscript_Charts: source-controlled long-form plotting data for manuscript figures and Executive Snapshot use.
- 121_Manuscript_Figure_Map: figure-to-chart-key, source-sheet, renderer and data-readiness map for manuscript figures.

Appendix B - Data Provenance and Figure Register

The companion evidence database is the machine-readable source register for this manuscript. It integrates the resource, economics, regional, scenario, chronology, current-system and realized-performance evidence used across the chapters, including TSEP/KAPCO grid evidence, the CY2026 system-cost forecast, 2026 QASPL/Karot/Bhikki tariff calibration, bankability screening, locational-value architecture and the unresolved primary-data model gates. Reported values, derived screening calculations, prototype DCF outputs and integrated-synthesis findings remain explicitly separated by data type.

Reproducibility note

The manuscript figures should be regenerated whenever the underlying database is updated. The plotted values are not hand-entered into the Word document; the Word figures are snapshots of the current database version. This keeps narrative, figures and source provenance synchronized.

Appendix C – Glossary of Terms, Abbreviations and Units

A. Core Analytical and Research Terms

Term	Definition as used in this synthesis
8,760-hour analysis / model	Chronological modelling of every hour in a normal 365-day year. It allows demand, generation availability, renewable variability, storage, hydrology, outages and transmission constraints to be represented in their actual time sequence.
Adaptation rather than imitation	Principle used in the international-comparator analysis. Pakistan should identify why a technology, institution or policy worked elsewhere and test whether the enabling conditions can be reproduced locally rather than copying another country's energy mix.
Analytical screening	Preliminary quantitative assessment used to identify promising options, sensitivities or evidence gaps without claiming a final investment or system-optimization result.
Baseline	Dated reference condition against which subsequent changes or scenarios are compared. The synthesis principally uses FY2024-25 as the complete recent annual energy baseline, supplemented by later 2025-26 evidence where available.
Commercial deliverability	Ability of a discovered or technically identified energy resource to be developed and sustain useful production at a practical rate, cost and timescale. A discovery alone does not establish commercial deliverability.
Commercial reserve	Portion of a discovered resource considered technically and economically recoverable under specified conditions. It is distinct from total geological or technical resource potential.
Comparator / comparator country	Country, project or international experience used to examine a particular function relevant to Pakistan, such as geothermal de-risking, hydro flexibility, grid integration or technology scale.
Comparative analogue	External case used because it shares a relevant process, technology, geology, financing mechanism or system function with the Pakistan question being investigated. It does not imply complete equivalence.
Current-system calibration	Adjustment or checking of analytical assumptions against recent observed system costs, tariffs, plant utilization, grid conditions or other contemporary evidence.
Decision gate	Explicit evidence or performance condition that should be satisfied before moving to a stronger conclusion, larger investment or later development stage.

Term	Definition as used in this synthesis
Decision-grade evidence	Evidence sufficiently complete and reliable to support an actual project or policy decision. Most screening cases in this study are deliberately not described as decision-grade.
Delivered system cost	Cost of providing useful electricity or energy to the system after considering relevant generation, transmission, integration, flexibility, curtailment, fuel, financing and other system costs. It is broader than plant-level LCOE.
Derived calculation	Value calculated by this study from reported inputs using a stated formula, such as an implied capacity factor or normalized cost. It is kept distinct from a directly reported observation.
Energy security	Ability of the energy system to provide reliable and affordable energy with manageable exposure to supply disruption, fuel-price volatility, foreign-exchange constraints, infrastructure failure and environmental or water limitations.
Energy self-reliance	Reduction of avoidable external dependence by using technically and economically defensible domestic resources. It does **not** mean complete autarky or elimination of all imports.
Energy-system resilience	Ability of the energy system to continue delivering essential services and recover from disruptions such as fuel shortages, extreme weather, hydrological variation, equipment failure, grid constraints or price shocks.
Evidence class	Category describing the origin and analytical status of information, such as measured observation, official statistic, derived value, model result or study interpretation.
Evidence gate	Rule preventing a model result from being interpreted more strongly than its supporting data justify. Missing CAPEX, O&M, tariff, resource or finance evidence can therefore gate a full economic evaluation.
Evidence hierarchy	Study framework giving greater weight to direct measurements, official records and reproducible evidence than to weaker secondary interpretations when addressing critical quantitative questions.
Evidence normalization	Adjustment of evidence to a common and transparent basis while preserving differences in year, currency, capacity definition, tariff scope and evidence type.
Forecast	Projection presented as an expected future outcome by its originating model or institution. The Synthesis distinguishes forecasts from its own exploratory scenarios.
Integrated synthesis	Evidence-weighted conclusion developed in this research after considering observations, calculations, models, published interpretations, competing explanations and uncertainty.
Living evidence framework	Database and analytical structure designed to be updated as new Yearbooks, project records, discoveries, tariffs, operating data and resource measurements become available.
Locational value	Economic value that depends on where a project is connected or located, including congestion relief, avoided transmission investment, reduction in losses, local reliability and access to demand.
Model / scenario output	Result produced by an optimization, forecast or scenario model rather than directly observed in the real system.
Observed / reported evidence	Directly published measured, regulatory, administrative or project value retained without treating it as a study calculation.
Portfolio	Combination of different resources, technologies, infrastructure and demand measures considered together because they provide complementary system functions.
Prospective case	Forward-looking project or technology case assessed before sufficient operating evidence exists.

Term	Definition as used in this synthesis
Prototype	Demonstration application used to establish analytical capability. A prototype DCF or Bankability Window should not automatically be interpreted as investment advice.
Published interpretation	Explanation or conclusion provided by another author, agency or institution rather than by this synthesis.
Regional differentiation	Recognition that resource quality, demand, water, transmission, terrain and infrastructure differ materially across Pakistan, requiring different regional portfolios.
Resource productivity	Amount of useful economic or energy service obtained from a unit of domestic fuel, renewable resource, water, infrastructure or capital.
Scenario	Transparent “what-if” representation used to examine consequences of specified assumptions. A scenario is not necessarily a forecast or policy target.
Screening scenario	Scenario intended to test direction, sensitivity or feasibility before detailed chronological or investment-grade modelling.
Sustainability	Multidimensional condition involving resource longevity, affordability, reliability, water, environmental effects, infrastructure and financing. The Synthesis explicitly avoids treating “sustainable” as synonymous with only “renewable” or “low-carbon.”
System value	Total contribution of a resource or project to the energy system, including energy, capacity, reliability, flexibility, avoided fuel imports, grid support, congestion relief or other services.
Technical potential / technical resource	Quantity that could potentially be exploited on technical grounds before full economic, environmental, infrastructure or commercial constraints are applied.
Transferability	Degree to which a lesson, mechanism or technology demonstrated elsewhere can reasonably be applied under Pakistan-specific geological, economic, institutional, grid and water conditions.
Transferable system function	Specific capability learned from another country, such as reservoir flexibility, geothermal exploration-risk sharing or high-VRE integration, rather than copying that country's overall fuel shares.
Unknown / not reported	Evidence field for which no defensible value has been obtained. In the research database such values should remain blank rather than being entered as zero.
Water-energy nexus	Interdependence between energy production and water resources, including hydropower, cooling, groundwater pumping, geothermal reinjection and the energy required for water extraction and treatment.

B. Project Economics, Finance and Bankability

Term / abbreviation	Definition
Bankability	Ability of a project to attract financing because expected revenues, risks and cash flows are sufficient to satisfy investors and lenders under credible assumptions.
Bankability gap	Difference between the revenue required by investors/lenders and the value or tariff that the system or consumer can reasonably support.
Base case	Central set of assumptions against which favourable and downside cases are compared.
Breakeven tariff	Electricity price required for a project to reach a specified financial threshold, commonly NPV = 0 or a target return.
CAPEX – Capital Expenditure	Upfront investment associated with development, engineering, equipment, construction, site works, interconnection and other capital items.
Capital intensity	Project capital cost normalized by installed capacity, commonly USD/kW or USD/MW. It is useful for comparison but does not by itself measure overall economic attractiveness.

Term / abbreviation	Definition
Cash flow	Money entering or leaving a project during each period, including investment, operating revenues, operating costs, financing, taxes and terminal items.
Consumer/system ceiling	Maximum economically rational revenue or tariff that the power system or consumer can support after considering alternatives, avoided costs, reliability and system value.
DCF – Discounted Cash Flow	Financial analysis that converts future project cash flows into present values using a discount rate.
Debt/equity ratio	Proportion of project financing provided by borrowed capital versus shareholder capital.
Debt service	Scheduled repayment of debt principal and interest.
Debt tenor	Length of time over which project debt is scheduled to be repaid.
De-risking	Measures designed to reduce a project's risk or allocate it to the party best able to manage it, potentially reducing financing cost.
Development CAPEX	Capital spent before or during project development, including studies, permits, resource confirmation and other pre-construction activities.
Downside case	Stress scenario using assumptions less favourable to project economics than the base case.
DSCR – Debt Service Coverage Ratio	Ratio of cash available for debt service to required debt payments. A ratio above 1.0 indicates that available cash exceeds scheduled debt service.
EMV – Expected Monetary Value	Probability-weighted value of uncertain outcomes. Particularly relevant to geothermal exploration where unsuccessful and successful drilling outcomes have different costs and values.
EPC – Engineering, Procurement and Construction	Contracting or cost scope covering engineering design, equipment/material procurement and project construction.
Equity IRR	Internal rate of return calculated on cash flows attributable to equity investors after debt financing effects.
Evidence-gated economics	Economic modelling approach in which calculations are withheld or explicitly qualified if critical sourced inputs are incomplete.
Fixed O&M	Operations and maintenance costs that do not vary substantially with annual generation, commonly expressed per year or per unit of installed capacity.
Full-life economics / full-life DCF	Project evaluation incorporating development/construction investment and the complete operating life rather than considering only future remaining-life cash flows.
Grace period	Initial period during which debt principal, and sometimes other debt obligations, may be deferred.
Historical reconstruction	Rebuilding the economics of an existing project from historical CAPEX, tariff, financing and operating evidence for analytical comparison.
Hurdle rate	Minimum return required by an investor before accepting a project.
Indexation	Mechanism that adjusts tariff components over time according to specified variables such as inflation, exchange rate, fuel price or interest-rate indices.
Investor floor	Minimum tariff or revenue required for the project to meet specified investor-return and/or debt-service criteria.
Investor-Consumer Bankability Window	Framework comparing the **investor floor** with the **consumer/system ceiling**. A viable window exists when investor-required revenue can be accommodated within defensible system value. This is a central study-specific concept.
Investment-grade analysis	Economic assessment supported by sufficiently complete technical, contractual, financing and operating information to underpin an actual investment decision.
IRR – Internal Rate of Return	Discount rate at which the NPV of project cash flows equals zero.

Term / abbreviation	Definition
LCOE – Levelized Cost of Electricity	Present value of lifetime electricity-related costs divided by present value of lifetime electricity generation. It is a plant-level metric and does not automatically include all grid or system costs.
LCOS – Levelized Cost of Storage	Lifetime cost of providing stored electricity or storage service, normally including capital cost, O&M, efficiency losses, replacement and throughput assumptions.
Mean	Arithmetic average of model or Monte Carlo outcomes.
MIRR – Modified Internal Rate of Return	Return metric that modifies conventional IRR by explicitly assuming financing and reinvestment rates.
Monte Carlo simulation	Repeated calculation using probability distributions for uncertain inputs to produce a distribution of possible economic outcomes.
NPV – Net Present Value	Present value of future project cash inflows minus present value of project cash outflows at a specified discount rate.
O&M – Operations and Maintenance	Costs required to operate, maintain and repair an asset. May be divided into fixed and variable components.
OPEX – Operating Expenditure	Recurring expenditure incurred during project operation.
Owner's cost	Project-development and implementation costs incurred by the project owner outside the principal EPC contract.
P10 / P50 / P90	Percentiles of a probability distribution. Their practical “upside/downside” meaning depends on whether the output is a cost or value variable; the study therefore labels the direction explicitly.
Payback period	Time required for cumulative project cash flows to recover the initial investment under the specified methodology.
Point-forward economics	Evaluation of future cash flows from the current date onward. Historical expenditure already incurred is treated as sunk rather than re-spent.
PPA – Power Purchase Agreement	Contract governing the sale and purchase of electricity, normally specifying tariff/revenue arrangements and contractual obligations.
Project vintage	Period in which a project was developed and financed. Vintage matters because technology cost, financing conditions, exchange rates and tariff structures change over time.
Procurement-cost proxy	Derived approximate cost per unit of purchased electricity based on reported procurement components. It is not automatically equivalent to LCOE or a project tariff.
Risk allocation	Assignment of individual risks to the developer, lender, government, insurer, offtaker or another party according to ability to control or absorb them.
ROE – Return on Equity	Return earned or required on shareholder capital.
Sensitivity analysis	Testing how an economic result changes when one or more assumptions are varied.
Sunk cost / sunk CAPEX	Historical expenditure already incurred and therefore not treated as a new future cash outflow in a point-forward evaluation.
Tariff	Price or revenue structure under which electricity or an energy service is purchased or sold.
Tornado sensitivity chart	Sensitivity plot ranking input variables according to their effect on a chosen result such as NPV or LCOE.
Two-way sensitivity	Analysis in which two uncertain variables are varied simultaneously to show their combined effect on a result.
Variable O&M	Operating and maintenance cost that varies with electricity generation or plant use.
WACC – Weighted Average Cost of Capital	Weighted required return on debt and equity financing, often used as a project discount-rate reference.

The manuscript deliberately begins economics with annual cash flow rather than LCOE alone and includes development, EPC, grid, water, financing, O&M, fuel, taxes and other relevant components.

C. Tariff and Regulatory-Economics Terms

Term / abbreviation	Definition
CPP – Capacity Purchase Price	Payment associated principally with making generating capacity available rather than the quantity of electricity actually produced.
EPP – Energy Purchase Price	Payment linked primarily to energy actually generated or purchased.
CPP + EPP	Combined capacity and energy purchase-cost components used in parts of the Synthesis as an observed procurement-cost proxy.
FCC – Fuel Cost Component	Fuel-related portion of a power tariff or electricity cost. It must not be interpreted as the complete plant tariff.
Fuel-price exposure	Sensitivity of plant or system cost to changes in fuel prices.
FX – Foreign Exchange	Currency-exchange exposure, particularly PKR versus foreign currencies used for fuels, debt, imported equipment or indexed tariff components.
FX exposure	Financial risk arising when project costs or revenues depend on currency exchange rates.
Power Purchase Price / PPP	In the relevant NEPRA context of this manuscript, the aggregate power-purchase price or forecast purchase cost; it should not be confused with “public-private partnership.”
Tariff indexation	Adjustment of tariff components according to agreed inflation, exchange-rate, fuel-price or other indices.
Tariff petition	Formal application requesting approval of a tariff, often containing detailed cost and financing assumptions.

D. Power-System, Grid, Reliability and Storage Terms

Term / abbreviation	Definition
Ancillary services	Grid-support services needed in addition to energy supply, such as frequency control, reserves, voltage support and system balancing.
Availability	Proportion of time a generating unit or system is technically capable of operating, regardless of whether it is dispatched.
Availability factor	Available operating time or capacity expressed as a percentage of the total possible period.
Behind-the-meter generation	Electricity generated on the consumer's side of the utility meter, much of which may not appear as grid-supplied generation.
BESS – Battery Energy Storage System	Battery installation capable of charging electricity, storing it and later discharging it to provide energy or grid services.
Busbar cost	Cost of electricity at the generating plant connection point before wider transmission, distribution and system-integration costs.
Capacity adequacy	Ability of the installed and reliably available resource portfolio to meet peak demand and reserve needs.
Capacity factor / CF	Actual energy produced during a period divided by the energy that would have been produced if the plant operated at rated capacity continuously.
Capacity payment	Payment made for availability or contracted capacity, independent wholly or partly of actual energy produced.
Capacity-cost dilution	Increase in fixed or capacity cost per delivered kWh when a plant operates at relatively low utilization but fixed payments remain.

Term / abbreviation	Definition
Congestion	Condition in which transmission capacity is insufficient to transfer all economically desirable power between locations.
Curtailment	Reduction of available generation because the system cannot or should not accept the full output, commonly because of grid, balancing or demand constraints.
Demand response	Deliberate modification of electricity demand in response to price, grid conditions or control signals.
Dispatch	Instruction or decision determining which generating resources operate, how much they generate and when.
Distributed generation	Small or medium generation located close to consumers rather than at large centralized power stations.
Economic dispatch	Scheduling generation to meet demand while minimizing operating cost subject to technical and system constraints.
EENS – Expected Energy Not Served	Reliability metric estimating the expected amount of electricity demand that cannot be supplied over a specified period.
EHV – Extra-High Voltage	High-voltage transmission level used for bulk transfer of electricity over long distances.
Electrification	Replacement or expansion of energy services through electricity, for example electric transport, heating or industrial processes.
Energy arbitrage	Charging storage when electricity is relatively inexpensive and discharging it when electricity has greater economic value.
Energy spread	Difference between electricity values or prices at charging and discharging times; one potential source of storage value.
Evacuation	Transmission of electricity away from a generating station or resource area into the wider grid.
Firm capacity / firming	Capacity or complementary resource able to support reliable supply when variable generation is unavailable or demand is high.
Flexibility	Ability of generation, storage, networks or demand to change output or consumption in response to system conditions.
Frequency support	Service helping maintain electric-system frequency close to its required operating level.
Generation	Electrical energy actually produced over a period, usually expressed in kWh, MWh, GWh or TWh.
Grid hosting capacity	Amount of additional generation or load that a network can accommodate without unacceptable operational or infrastructure problems.
Gross capacity	Generator capacity before deduction of electricity used internally by the plant.
Gross generation	Total electricity produced at generator terminals before station-use deductions.
HVDC – High-Voltage Direct Current	Transmission technology using direct current at high voltage, particularly suited to large power transfers over long distances or controlled interconnections.
Installed capacity / nameplate capacity	Rated power-generating capability of installed equipment, normally in MW or GW. It does not indicate how much energy the plant actually produces.
Interconnection	Physical grid connection linking a generator, storage facility, region or power system with another part of the network.
Load	Electrical demand being supplied at a particular time.
Load factor	Average demand divided by peak demand over a specified period.
LOLE – Loss of Load Expectation	Reliability measure describing the expected duration or frequency with which demand exceeds available supply capability.
Maximum demand / peak demand	Highest level of electricity demand observed or projected during a specified period.

Term / abbreviation	Definition
Net capacity	Capacity available for export to the grid after subtracting plant auxiliary consumption.
Net load	Electricity demand remaining for dispatchable resources after subtracting variable or non-dispatchable generation, commonly solar and wind.
Net metering	Billing arrangement under which eligible consumers with distributed generation can export electricity to the grid and receive credit according to applicable rules.
Network deferral	Avoidance or postponement of transmission or distribution investment because another intervention reduces the need for that upgrade.
Nodal constraint	Transmission limitation associated with a specific grid location or node.
Power rating	Maximum instantaneous output or charging/discharging capacity of a storage or generation asset, usually in MW.
PSH – Pumped-Storage Hydropower	Storage technology that pumps water to an upper reservoir when energy is available and releases it through turbines when electricity is needed.
Ramp rate	Rate at which a generator, storage system or demand resource can increase or decrease power.
Reactive power	Component of AC power used to support electric and magnetic fields and maintain system voltage.
Reserve margin	Available generating capacity above expected peak demand, used as one adequacy indicator.
Round-trip efficiency	Energy discharged from storage divided by energy used to charge it over a complete charge-discharge cycle.
Service stack	Combination of multiple revenues or system functions supplied by a storage or other flexible asset, such as energy shifting, reserve, congestion relief and frequency support.
Sent-out generation	Electricity exported from a generating station after deducting the plant's own auxiliary consumption.
STATCOM – Static Synchronous Compensator	Power-electronics device used to provide fast reactive-power and voltage support to an electricity network.
Storage duration	Stored energy divided by rated power, usually expressed in hours; for example, a 100 MW / 400 MWh battery has approximately four hours of duration.
T&D – Transmission and Distribution	Network systems that transport electricity from generators to end users.
T&D losses	Electricity lost in transmission and distribution between supply and final delivery, subject to the accounting boundary used by the source.
Transmission reinforcement	Upgrade or addition to the transmission network designed to increase transfer capability, reliability or resource integration.
Utilization factor	Degree to which a generating asset or portfolio is actually used relative to its available or rated capability; source definitions may differ and must be preserved.
Voltage support	Provision of reactive power or other control actions to maintain acceptable network voltage.
VRE – Variable Renewable Energy	Renewable generation whose short-term output varies with natural conditions, principally solar PV and wind.

E. Energy Technologies and Resource Terms

Term / abbreviation	Definition
Bagasse	Fibrous residue remaining after sugar-cane processing, used as a biomass fuel, particularly for cogeneration in sugar mills.

Term / abbreviation	Definition
Bioenergy	Energy derived from biological materials such as crop residues, bagasse, biogas or organic waste.
Binary geothermal / binary-cycle plant	Geothermal plant in which geothermal fluid transfers heat through a heat exchanger to a secondary working fluid that drives a turbine.
CCGT – Combined-Cycle Gas Turbine	Power plant combining gas-turbine and steam-cycle generation to improve thermal efficiency.
Closed-loop geothermal	Geothermal concept circulating working fluid through sealed subsurface wells or loops without producing reservoir fluid in the conventional hydrothermal manner.
Coal	Solid fossil fuel. In this Synthesis a distinction is made between indigenous/local coal, particularly Thar lignite, and imported coal.
Cogeneration / CHP	Simultaneous production of useful electricity and heat from the same fuel or energy source. Bagasse projects may therefore have value beyond electricity alone.
CSP – Concentrated Solar Power	Solar technology concentrating sunlight to produce heat, generally used to generate electricity through a thermal cycle.
Direct geothermal heat / direct use	Use of geothermal heat directly for heating, agriculture, drying, industry, aquaculture or other thermal services without first converting it to electricity.
Dry-steam geothermal	Geothermal system in which natural steam can be supplied relatively directly to a turbine.
EGS – Enhanced Geothermal System	Geothermal development in which engineering techniques are used to create or improve subsurface fluid circulation through hot rock where a conventional productive hydrothermal reservoir is absent or inadequate.
Flash-steam geothermal	Power-generation method in which high-temperature geothermal fluid undergoes a pressure reduction so part of the liquid flashes to steam and drives a turbine.
Geothermal energy	Useful heat contained within the Earth that can be exploited for electricity or direct thermal use.
Hydel	Term commonly used in Pakistan for hydroelectric generation; effectively synonymous with hydropower in this document.
Hydropower	Electricity generated by converting hydraulic head and water flow into mechanical and electrical energy.
Hydrothermal geothermal	Naturally occurring geothermal system containing hot water and/or steam capable of transferring subsurface heat. It is entirely distinct from hydropower.
Hybrid energy system	Integrated combination of more than one generation or storage technology, such as solar-wind-storage or solar-wind-HVDC development.
Lignite	Low-rank coal with relatively high moisture content. Pakistan's major Thar coal resource is predominantly lignite.
Li-ion – Lithium-ion battery	Rechargeable battery chemistry widely used in modern utility-scale battery storage systems.
Nuclear power	Electricity generation using heat released by controlled nuclear fission.
Offshore wind	Wind generation installed in marine or large-water environments rather than on land.
Onshore wind	Wind generation installed on land.
ORC – Organic Rankine Cycle	Binary thermodynamic cycle using an organic working fluid with a lower boiling point than water; commonly considered for medium-temperature geothermal resources.
PV – Photovoltaic	Technology that converts sunlight directly into electricity using semiconductor solar cells.
Solar PV	Electricity generation using photovoltaic modules.
Thermal generation	Electricity produced from heat, usually through combustion, nuclear fission or another thermal process.

Term / abbreviation	Definition
Waste-to-energy	Recovery of useful energy from municipal or other waste streams, evaluated in this study together with waste-management requirements.
Wind power	Electricity generated by converting the kinetic energy of moving air through wind turbines.

F. Geothermal, Geological and Subsurface Terms

Term	Definition
Anticlinorium	Large regional structure consisting of an overall arch or anticline containing multiple smaller folds; used in reference to the Zindapir Anticlinorium geothermal study area.
Brine	Saline subsurface fluid, including geothermal reservoir water containing dissolved minerals.
Cascade use	Sequential use of geothermal heat at progressively lower temperatures, allowing one resource to serve several thermal applications.
Exploration risk	Probability and economic consequence that subsurface exploration fails to discover a resource of sufficient temperature, permeability, flow or size.
Geothermal gradient	Rate at which subsurface temperature increases with depth, generally expressed in °C/km.
Geothermal manifestation	Surface indication of subsurface geothermal activity, such as a hot spring, warm spring, fumarole or altered ground.
Geothermal prospect	Area where existing geological, geochemical or thermal evidence indicates potential geothermal resources but commercial productivity has not yet been demonstrated.
Heat flow	Rate at which thermal energy passes through a unit area of the Earth's surface, commonly expressed in mW/m².
Injectivity	Ability of a formation or well to accept injected fluid at a sustainable rate and pressure.
Permeability	Ability of rock or sediment to transmit fluids through connected pore spaces or fractures.
Reinjection	Return of produced geothermal fluid to the subsurface to support reservoir pressure, manage disposal and improve resource sustainability.
Reservoir	Subsurface rock volume capable of storing and transmitting economically relevant fluids or heat.
Reservoir confirmation	Acquisition of direct evidence that a prospective subsurface resource has adequate temperature, flow, permeability, pressure and other characteristics for development.
Reservoir management	Long-term control of production, reinjection, pressure and well operation to sustain resource performance.
Resource confirmation well	Well drilled or tested specifically to establish whether a prospective resource is commercially productive.
Thermal gradient	See **geothermal gradient**.
Zindapir	Principal open-access integrated geothermal/geophysical case used in this Synthesis for Pakistan screening; it remains an evidence case rather than a proven commercial geothermal field.

G. Petroleum, Gas and Upstream Terms

Term / abbreviation	Definition
Appraisal well	Well drilled after a discovery to define the size, continuity, properties and commercial potential of the accumulation.
Brownfield development / productivity	Additional investment or operational improvement in an already developed field or facility to maintain or increase production or efficiency.
Crude oil	Naturally occurring liquid petroleum before refining.
Development well	Well drilled within a known commercial accumulation to produce hydrocarbons or support field development.
Discovery	Identification of a previously unrecognized hydrocarbon accumulation. A discovery does not automatically constitute commercially recoverable reserves.
Exploratory / exploration well	Well drilled primarily to test for hydrocarbons in a prospect not previously proven by drilling.
Field redevelopment	Additional investment in an existing oil or gas field to improve recovery, restore production or access remaining reserves.
Gas deliverability	Rate at which gas reserves can actually be produced and supplied to consumers or infrastructure.
Indigenous gas	Natural gas produced domestically within Pakistan.
LNG – Liquefied Natural Gas	Natural gas cooled to a liquid state for transport or storage. Pakistan imports LNG and regasifies it before pipeline use.
Natural gas	Gaseous hydrocarbon fuel, predominantly methane.
Petroleum group	Statistical trade grouping used in Pakistan sources covering petroleum-related imports; its precise scope follows the reporting source.
Petroleum products	Refined products derived from crude oil, such as petrol, diesel, kerosene and furnace oil.
Reserve replacement	Addition of new commercially recoverable reserves relative to volumes depleted through production.
RFO – Residual Furnace Oil	Heavy residual petroleum fuel used in some thermal power plants.
RLNG – Regasified Liquefied Natural Gas	Imported LNG converted back to gaseous form for transmission and domestic consumption. The synthesis distinguishes imported LNG expenditure from domestic RLNG consumption.
Upstream	Oil and gas activities associated with exploration, appraisal, field development and production rather than refining, transport or retail.
Upstream deliverability	Actual ability of discovered domestic oil or gas resources to move from reserves through development into sustained production.

H. Hydropower, Water and Environmental Terms

Term	Definition
Dry-year risk	Risk that hydropower production or water availability is materially lower during years of below-normal inflow.
Gross storage	Total physical reservoir storage volume between defined reservoir limits.
Hydraulic head	Difference in water elevation or pressure that provides the driving force for hydropower generation.
Hydrology	Study of the occurrence, movement and variability of water, including river flow, inflow and reservoir behaviour.

Term	Definition
Inflow chronology	Time sequence of water entering a reservoir or hydropower system.
Live storage	Portion of reservoir storage that can normally be withdrawn or actively managed for operational purposes.
Water Compatibility Index	Semi-quantitative framework proposed in the Synthesis to compare water source, withdrawal, consumption, salinity, treatment, cooling, reinjection, competing uses, water stress and related technology-specific issues.
Water consumption	Portion of withdrawn water not returned to the immediate source because of evaporation, incorporation into products or another consumptive process.
Water withdrawal	Total water removed from a source for use by a project, whether or not part of it is later returned.
Water stress	Condition in which water demand and competing use place significant pressure on available water resources.

I. Planning, Policy and Institutional Abbreviations

Abbreviation / term	Definition
ADB	Asian Development Bank.
AJK	Azad Jammu and Kashmir.
AJKPDO	Azad Jammu and Kashmir Power Development Organization, as referenced in the Energy Yearbook producer grouping.
AQUASTAT	FAO's global water-information system and database.
ATB – Annual Technology Baseline	Technology-cost and performance reference produced by NREL and partner institutions; used in the synthesis for selected benchmark assumptions such as battery storage.
BEST-PAK	World Bank-supported Pakistan energy/grid programme under which the Grid Stability Enhancement Project is discussed in the Synthesis.
CPPA-G	Central Power Purchasing Agency (Guarantee) Limited, associated with power purchasing and settlement in Pakistan's power sector.
DISCO	Electricity distribution company.
DOE	United States Department of Energy.
ESMAP	Energy Sector Management Assistance Program, administered by the World Bank.
FAO	Food and Agriculture Organization of the United Nations.
HDIP	Hydrocarbon Development Institute of Pakistan.
IAEA	International Atomic Energy Agency.
IEA	International Energy Agency.
IFC	International Finance Corporation, member of the World Bank Group.
IGCEP – Indicative Generation Capacity Expansion Plan	Pakistan power-sector planning framework for future generation-capacity requirements and composition.
IPP – Independent Power Producer	Privately developed/operated electricity-generation project selling electricity under contractual or market arrangements.
IRENA	International Renewable Energy Agency.
IRSA	Indus River System Authority.
ISMO – Independent System and Market Operator	Pakistan institution responsible for system and market-operation functions referenced in the current planning evidence.

Abbreviation / term	Definition
ISP – Integrated System Plan	Integrated electricity-system planning framework combining generation and related system requirements; the Synthesis uses the 2025-35 plan as a near-term planning anchor.
KAPCO	Kot Addu Power Company; used in the Synthesis as a case illustrating locational and transmission-system value.
NDC – Nationally Determined Contribution	National climate commitment submitted under the Paris Agreement; Pakistan's NDC 3.0 is used as a contextual clean-energy planning reference.
NEECA	National Energy Efficiency & Conservation Authority.
NEPRA	National Electric Power Regulatory Authority.
NGC	National Grid Company, referenced with the current transmission/system-planning institutional structure.
NREL	National Renewable Energy Laboratory / National Laboratory of the Rockies references used for standardized technology data; the manuscript retains the source naming appropriate to the cited material.
NTDC	National Transmission and Despatch Company.
OGRA	Oil and Gas Regulatory Authority.
PAEC	Pakistan Atomic Energy Commission.
PBS	Pakistan Bureau of Statistics.
PC-I	Government of Pakistan project-planning and approval document containing project scope, cost, financing, schedule and related information.
PEDO	Pakhtunkhwa Energy Development Organization.
PPIB	Private Power and Infrastructure Board.
PRIS	IAEA Power Reactor Information System.
SBP	State Bank of Pakistan.
TSEP – Transmission System Expansion Plan	Formal transmission-network development plan used to identify transmission needs, projects and system constraints.
USAID	United States Agency for International Development.
WAPDA	Water and Power Development Authority.
World Bank / ESMAP	World Bank and its Energy Sector Management Assistance Program, sources of major Pakistan renewable-resource, grid, dispatch and geothermal-risk studies.

The manuscript explicitly ranks direct measurements, official Pakistani statistics and standardized international datasets according to evidence quality rather than treating all sources as equivalent.

J. Project and Company Abbreviations Used Repeatedly

Abbreviation	Definition
C-5	Chashma Nuclear Power Project Unit 5.
K-Electric	Vertically integrated electricity utility serving Karachi and surrounding areas.
QASPL	Quaid-e-Azam Solar Power project/company, used particularly for tariff-indexation evidence.
QATPL	Quaid-e-Azam Thermal Power project/company associated with the Bhikki RLNG CCGT case.
PTPL	Punjab Thermal Power project/company used in the RLNG project evidence set.

Abbreviation	Definition
JDW-II / JDW-III	Bagasse cogeneration plants associated with JDW Sugar Mills and used in the realized bioenergy-performance comparison.

K. Units, Currency and Statistical Notation

Unit / notation	Meaning
bbl/d	Barrels of oil per day.
CF	Capacity factor when used in performance tables.
CAGR – Compound Annual Growth Rate	Constant annualized growth rate that would connect a starting value to an ending value over a specified period.
CY	Calendar Year.
FY	Fiscal Year.
GW	Gigawatt = 1,000 MW = one billion watts.
GWh	Gigawatt-hour = one million kWh; unit of electrical energy.
GWh/yr or GWh/y	Gigawatt-hours per year.
kV	Kilovolt, equal to 1,000 volts; commonly used to describe transmission voltage.
kW	Kilowatt = 1,000 watts.
kWh	Kilowatt-hour, a unit of electrical energy.
MAF – Million Acre-Feet	Water-volume unit commonly used for reservoirs and river flows in Pakistan.
M2M exchange rate	SBP mark-to-market exchange-rate reference used in the Synthesis as a dated currency-conversion snapshot, not as a historical price-normalization method.
MMBbl	Million barrels.
MMBtu	Million British thermal units, widely used for gas and fuel pricing.
MMCFD / MMcf/d	Million cubic feet of gas per day.
MTOE	Million tonnes of oil equivalent, a common unit for comparing energy quantities across fuels.
MW	Megawatt = one million watts; unit of power or capacity.
MWh	Megawatt-hour = 1,000 kWh; unit of electrical energy.
MW/MWh storage notation	First value denotes storage power rating; second denotes stored-energy capacity. For example, 100 MW / 400 MWh corresponds approximately to four hours at rated output.
m^3/MWh	Cubic metres of water used or withdrawn per megawatt-hour of electricity; the exact interpretation depends on whether the metric represents withdrawal or consumption.
mW/m^2	Milliwatts per square metre; unit commonly used for terrestrial heat flow.
PKR	Pakistani rupee.
PKR/kW/h	Rupees per kW of capacity per hour; used for certain capacity-charge formulations.
PKR/kWh	Pakistani rupees per kilowatt-hour.
Tcf	Trillion cubic feet, commonly used for natural-gas reserves.
TWh	Terawatt-hour = 1,000 GWh; unit of large-scale electrical energy.
USD	United States dollar.
USD/kW	US dollars of capital cost per kilowatt of installed capacity.
USD/MWh	US dollars per megawatt-hour of electricity.
USc/kWh	US cents per kilowatt-hour.
°C/km	Degrees Celsius increase per kilometre of depth; common unit for geothermal gradient.
%	Percent.

Unit / notation	Meaning
Percentage point	Arithmetic difference between two percentages; for example, an increase from 20% to 25% is five percentage points, not a 5% relative increase.

L. Macroeconomic and Financing Indices

Term	Definition
CPI – Consumer Price Index	Measure of consumer-price inflation used in some tariff indexation arrangements.
KIBOR – Karachi Interbank Offered Rate	Pakistan money-market benchmark used in financing and tariff calculations.
SOFR – Secured Overnight Financing Rate	US dollar interest-rate benchmark used in international financing and some tariff/indexation structures.
PKR/USD	Exchange rate between the Pakistani rupee and United States dollar.
Foreign-currency debt	Debt denominated in a currency other than the principal domestic revenue currency, creating FX exposure.

M. Scenario Abbreviations Used in the 2040-2050 Framework

Code	Scenario	Meaning in the Synthesis
REF	**Reference Extension**	Extends the current/reference planning direction beyond the formal planning horizon and serves as a comparison case.
LCE	**Least-Cost + Efficiency**	Screening pathway combining lower demand growth, better load factor, efficiency and stronger low-cost/clean supply.
WAT	**Water-Constrained**	Pathway that places greater restrictions on freshwater-intensive expansion and shifts toward lower-water options.
IMP	**Import-Minimization**	Tests a system with very low direct imported-fossil generation while retaining reliability resources.
HRE	**High-Renewable**	Stress test with substantially greater solar/wind penetration and therefore greater flexibility requirements.
BAL	**Balanced Self-Reliance**	Integrated pathway balancing indigenous supply, efficiency, firm resources, renewables, flexibility and import reduction rather than maximizing one technology.
BAU – Business as Usual	Baseline or planning trajectory assuming continuation of broadly existing trends or assumptions; its precise meaning follows the originating planning source.	

N. Additional Terms Important to Interpretation of the Synthesis

Term	Definition
Avoided cost	Cost that the system does not have to incur because an alternative action is taken, such as avoided fuel, generation, transmission, capacity or losses.
Avoided fuel import	Reduction in imported fuel that results from domestic generation, efficiency or another intervention.
Brownfield productivity	Increased or sustained output from existing fields, plants or infrastructure through rehabilitation, optimization or additional investment.
Capacity versus generation	Capacity measures the maximum power rating in MW; generation measures actual energy produced through time in MWh/GWh/TWh. They must not be treated as interchangeable.
Energy efficiency	Provision of the same or improved energy service using less energy input.
Foreign-exchange exposure	Dependence of costs or payments on foreign currency because of imported fuels, equipment, financing or indexed contracts.
Fuel security	Reliability and affordability of obtaining required fuel in sufficient quantities.
Indigenous resource	Energy resource physically available within Pakistan, subject to technical and economic recoverability.
Import dependence	Degree to which domestic energy requirements rely on imported fuels, electricity, equipment or other energy inputs.
Low-carbon energy	Energy source associated with comparatively low operational greenhouse-gas emissions; the term does not automatically imply low cost, low water use or full sustainability.
Opportunity cost	Economic value of the best alternative use that must be forgone when a resource is used for a particular purpose. Water and gas can both carry substantial opportunity cost.
Reliability	Ability of the energy system to supply required demand within acceptable standards under normal and contingency conditions.
Reserve replacement ratio/concept	Comparison between additions to commercially recoverable reserves and volumes depleted through production. The Synthesis emphasizes that reserves must also be deliverable.
System ceiling	See **consumer/system ceiling**.
System integration	Technical and economic process of combining generation, storage, networks and demand so that the overall electricity system remains stable, reliable and efficient.
Technology-neutral comparison	Evaluation based on common performance, cost and system-value criteria while preserving technology-specific risks and functions rather than presuming one technology is preferable.
Utilization	Extent to which an asset is actually used. Low utilization can materially increase fixed cost per delivered unit of electricity.