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Brill-Viz

Energy Policy Options For Pakistan

Comparative Learning, Economics, System Value and Decision Gates

A concise decision-support paper derived from the master synthesis

Sustainable Energy Systems and Energy Security in Pakistan

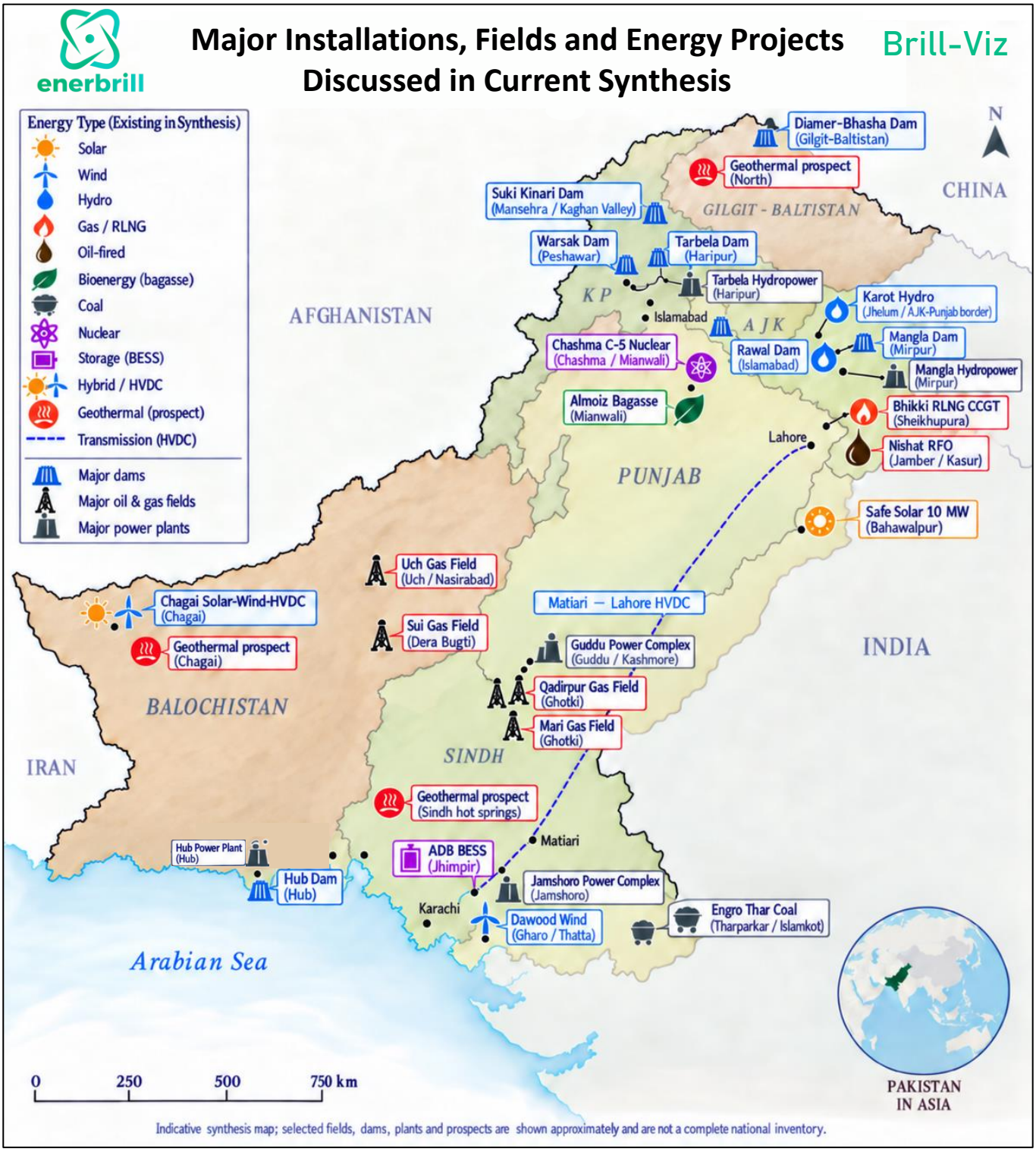
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Decision-use note

This paper presents evidence-supported policy options, economic tests, international comparator lessons and decision conditions. It does not rank technologies, prescribe a single national mix or treat a foreign energy mix as a target for Pakistan. International comparisons are used to identify transferable functions and enabling conditions; screening and comparator-derived economics remain distinct from observed project evidence.


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Major Installations, Fields and Energy Projects Discussed in Current Synthesis
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Energy Type (Existing in Synthesis)
Solar
Wind
Hydro
Gas / RLNG
Oil-fired
Bioenergy (bagasse)
Coal
Nuclear
Storage (BESS)
Hybrid / HVDC
Geothermal (prospect)
Transmission (HVDC)
Major dams
Major oil & gas fields
Major power plants
N
Diamer-Bhasha Dam (Gilgit-Baltistan)
Geothermal prospect (North)
CHINA
Suki Kinari Dam (Mansehra / Kaghan Valley)
GILGIT - BALTISTAN
Warsak Dam (Peshawar)
Tarbela Dam (Haripur)
Tarbela Hydropower (Haripur)
KP
AFGHANISTAN
Islamabad
AJK
Karot Hydro (Jhelum / AJK-Punjab border)
Chashma C-5 Nuclear (Chashma / Mianwali)
Rawal Dam (Islamabad)
Mangla Dam (Mirpur)
Mangla Hydropower (Mirpur)
Almoiz Bagasse (Mianwali)
Bhikki RLNG CCGT (Sheikhupura)
Lahore
Nishat RFO (Jamber / Kasur)
PUNJAB
Safe Solar 10 MW (Bahawalpur)
Uch Gas Field (Uch / Nasirabad)
Chagai Solar-Wind-HVDC (Chagai)
Matiari — Lahore HVDC
Sui Gas Field (Dera Bugti)
Geothermal prospect (Chagai)
Guddu Power Complex (Guddu / Kashmore)
INDIA
Qadirpur Gas Field (Ghotki)
BALOCHISTAN
Mari Gas Field (Ghotki)
SINDH
IRAN
Geothermal prospect (Sindh hot springs)
Hub Power Plant (Hub)
ADB BESS (Jhimpir)
Matiari
Hub Dam (Hub)
Jamshoro Power Complex (Jamshoro)
Karachi
Dawood Wind (Gharo / Thatta)
Engro Thar Coal (Tharparkar / Islamkot)
Arabian Sea
0
250
500
750 km
PAKISTAN IN ASIA
Indicative synthesis map; selected fields, dams, plants and prospects are shown approximately and are not a complete national inventory.

Executive Summary

Pakistan's energy-security problem is a portfolio, resource-productivity and system-economics problem rather than a shortage of one technology. The Pakistan Energy Yearbook 2024-25 provides the complete annual bridge: indigenous energy production was about 50 MTOE, energy imports about 34 MTOE, and gross electricity generation 140.42 TWh in FY2024-25. The master synthesis shows that domestic-resource deliverability, project CAPEX, utilization, fuel and foreign-exchange exposure, capacity payments, grid constraints, water, financing and consumer affordability can materially change apparent economics. The policy framework therefore asks how Pakistan can obtain more reliable and affordable energy service from each unit of domestic resource, imported fuel, water, infrastructure and invested capital, rather than treating installed capacity or a single fuel share as the primary security metric.

- Observed current/recent Pakistan evidence is kept separate from proposed-project evidence, international benchmarks and scenario assumptions.
- International comparisons are used as functional learning cases, not as national fuel-share targets. India, China and the United States remain useful macro comparators for regional scale, indigenous-resource use, technology-led supply shifts and system development; more specialized comparators are used for geothermal risk, VRE integration, hydro flexibility, direct heat and financing mechanisms.
- Existing assets are evaluated primarily on point-forward economics; historical CAPEX is retained for audit but is not re-spent in the current year.
- New/proposed projects use full-life DCF only when CAPEX, O&M, financing, revenue/tariff and technology-specific inputs are sufficiently sourced.
- The Brill-Viz validation set separates full-life historical/investment reconstruction from point-forward existing-asset economics. Only Safe Solar has Full-DCF evidence gate = Yes; other project results remain screening-only or explicitly gated where critical current inputs are incomplete.
- Continued oil and gas exploration, field redevelopment and reserve replacement remain part of the energy-security evidence chain, while diversification and efficiency are tested for their ability to reduce unnecessary depletion and import/FX exposure where technically and economically defensible.
- The Investor-Consumer Bankability Window remains the central decision test: investor-required revenue is compared with defensible system/consumer value rather than with LCOE alone.
- P10/P50/Mean/P90 uncertainty and explicit fuel/FX/financing stress are used to show how conclusions change under uncertainty, while missing 8,760-hour and project-specific evidence remains visible rather than being replaced by unsupported assumptions.

Source basis: master synthesis and companion economics workbook; official Pakistan regulatory/project evidence; IRENA/IEA/World Bank/ADB/NREL benchmarks; and the synthesis source register. Khan, M. R. (2024) is retained as a conceptual starting point for the Pakistan-India-China-USA comparison, not as the primary national statistical evidence base. No new independent national least-cost result is introduced in this paper.

The FY2024-25 Yearbook also sharpens the efficiency and hydrocarbon-security case: public-utilities T&D losses were 35,316 GWh (23.8% of net supply); domestic oil and gas production remained below 2019-20 levels; exploration/appraisal drilling and discoveries continued; oil reserves declined modestly while reported gas reserves increased. The policy issue is therefore not simply depletion versus discovery, but whether exploration, reserve replacement, field redevelopment, existing assets, network-efficiency gains and alternative indigenous resources translate into reliable domestic deliverability quickly enough to reduce avoidable import and foreign-exchange exposure. In this paper, sustainability means maintaining useful energy services without creating an unmanageable dependence on finite fuels, imported energy, water, network capacity or unaffordable finance; energy security means maintaining those services under resource, price, hydrological, infrastructure and financing shocks.

1. Decision Context

The current evidence does not support one universal “best” technology for Pakistan. Regional resource quality, grid access, water, demand density, financing and existing infrastructure differ materially across Punjab, Sindh, Balochistan, Khyber Pakhtunkhwa, Gilgit-Baltistan and Azad Jammu and Kashmir. The decision problem is therefore to identify where each resource or intervention becomes physically suitable, financially bankable and system-useful under explicit conditions. International experience is used to clarify those conditions, not to import another country's fuel percentages or institutional model unchanged.

1.1 Contribution relative to previous Pakistan energy literature and evidence frameworks

Pakistan's energy literature and official planning documents provide complementary but distinct foundations for understanding the country's energy system. The Pakistan Energy Yearbook 2024-25 provides the principal current statistical baseline for indigenous energy production, imports, electricity generation, consumption, fuel supply and other national energy indicators, while the Pakistan Energy Outlook 2021-2030 provides an important forward-looking planning and demand-supply perspective. Peer-reviewed and analytical studies provide additional resource, technology and policy perspectives. Kanwal, S. et al., (2020) reviewed Pakistan's renewable-energy potential, including solar, wind, biomass, geothermal resources and smart-grid development, and emphasized stronger renewable-energy integration. Khan (2024) subsequently compared Pakistan's energy mix with India, China and the United States and highlighted the relationship between indigenous-resource utilization, energy imports and energy security; in the present study, this comparison is treated as a conceptual starting point rather than as the primary quantitative evidence base.

The present paper builds on this broader body of official data, planning studies, peer-reviewed literature, regulatory and project evidence, and international technical and economic benchmarks, rather than on any single earlier publication. Its contribution is to integrate these evidence streams within a common decision framework that considers domestic-resource deliverability, utilization, import and foreign-exchange exposure, water availability, transmission constraints, project finance, uncertainty and consumer/system value simultaneously.

Accordingly, the paper complements rather than replaces previous resource assessments, energy reviews and national planning studies. It extends the analytical question from what resources exist and how much energy they might provide toward the conditions under which a resource, project, existing asset, network investment or efficiency intervention becomes technically useful, financially bankable and economically defensible within Pakistan's energy system. Observed Pakistan evidence, proposed-project evidence, comparator-derived scenarios and illustrative stresses are therefore kept explicitly separate. This evidence classification, combined with the associated economic and system decision gates, constitutes the paper's principal methodological contribution.

1.2 Evidence and analytical method

The evidence hierarchy has four layers: (1) official and recent Pakistan records and regulatory/project documents; (2) project-specific sourced evidence such as tariffs, petitions, PC-I/appraisal and financing materials; (3) standardized international benchmarks and functional comparator cases; and (4) transparent illustrative assumptions used only for stress testing. Values from different periods or accounting boundaries are not merged without reconciliation, and prospective comparator-derived values are not presented as observed Pakistan project costs.

Existing assets are assessed primarily on point-forward or remaining-life economics, so sunk historical CAPEX is not re-spent. New or proposed projects use full-life discounted cash flow only when CAPEX, O&M, financing, tariff/revenue and technology-specific inputs are sufficiently sourced. NPV, IRR, DSCR, LCOE, investor-floor and sensitivity/uncertainty outputs are used as decision-support metrics with explicit evidence gates. Where 8,760-hour chronology, nodal data or project inputs are incomplete, the result remains a screening case rather than a least-cost system conclusion or investment recommendation.

1.3 Four economics case classes

Table 1.1: Economics case classes, evidence bases and permitted interpretations.

Case basis	Primary evidence	Permitted economic interpretation	Boundary
Observed / existing	Pakistan plant/project/tariff/operating evidence	Historical reconstruction; current or remaining-life economics	Historical CAPEX is not current-year CAPEX.
Pakistan proposed / sourced	PC-I, appraisal, tariff filing, financing or project documents	Full-life DCF when inputs close	Missing fields remain visible.
Comparator-derived Pakistan scenario	International benchmark/function + explicit Pakistan adjustments	Prospective screening; policy sensitivity; investor-floor testing	Scenario, not observed Pakistan cost.
Illustrative / screening	Transparent assumptions	Stress testing, mechanism testing, research design	Not financial-close or project-decision grade.

2. Current Economic Signals

The strongest current message is that utilization and cost structure matter as much as nameplate capacity. The FY2024-25 Yearbook provides the complete annual national baseline (HDIP, 2026), while 2026 regulatory decisions provide later/current price signals (NEPRA, 2026). Same-year or common-basis values below are useful screening signals, but they are not all equivalent measures: some are indexed tariffs, some are procurement-cost proxies and RFO is a fuel-cost component only.

Table 2.1: Current economic screening signals and principal interpretation cautions.

Case / signal	Screening value	What it represents	Main caution
CY2026 system	28.88 PKR/kWh	Official national power-purchase-price forecast	National average; not a project-specific system ceiling.
QASPL solar	17.71 PKR/kWh	Jan-Mar 2026 indexed tariff	Legacy 2015-vintage project; not new-build solar cost.
Karot hydro	25.89 PKR/kWh	Indexed equivalent at design annual energy	Fixed-charge conversion depends on actual generation.
Bhikki RLNG	22.07 PKR/kWh	Fuel + VOM + capacity at 92% availability	Structural screening proxy, not invoice.
Bhikki RLNG	24.91 PKR/kWh	Same structure at 42.5% utilization	Shows utilization/capacity-cost dilution effect.
RFO / Nishat	36.8213 PKR/kWh	Jan-2026 fuel-cost component	Fuel component only; not total tariff or LCOE.
Local Thar coal portfolio	~30.10 PKR/kWh	FY2024-25 observed procurement-cost proxy	Portfolio average; water/environment/new-build economics separate.
Imported coal portfolio	~65.61 PKR/kWh	FY2024-25 observed procurement-cost proxy	Low utilization materially raises fixed-cost intensity.
Nuclear fleet	~18.49 PKR/kWh	FY2024-25 observed procurement-cost proxy	Fleet operating evidence; not C-5 new-build tariff.
Bagasse portfolio	~32.33 PKR/kWh	FY2024-25 observed procurement-cost proxy	Large plant-level utilization differences.
ADB BESS proposal	US$250m lending envelope	Financing envelope for ~1,000 MW / 2,000 MWh concept	Not verified total installed CAPEX.

Sources: HDIP (2026), NEPRA performance and tariff decisions, PPIB public project records, ADB (2026), and the companion evidence database. Values are screening signals and must be read with the interpretation cautions shown.

2.1 System structure, efficiency and upstream-security signals

The Yearbook evidence (HDIP, 2026) adds a system-structure layer to the project-economics signals. These indicators are not project rankings; they identify where efficiency, demand structure, domestic-resource deliverability and import exposure should enter policy appraisal.

Table 2.2: FY2024-25 system-structure, efficiency and upstream energy-security signals.

Signal	FY2024-25 / trend evidence	Decision-use interpretation
Generation by producer group	IPPs 65,743 GWh; WAPDA 37,120; PAEC 24,208; total generation 140,420 GWh	Assess dispatch, contracts, grid access and fuel mix across institutional as well as technology categories.
End-use structure	Consumption 113,139 GWh; domestic 57,455; industrial 29,181; commercial 9,721; agriculture 5,882 GWh	Target efficiency, electrification and tariff/demand measures to observed sector behavior.
Network efficiency	T&D losses 35,316 GWh, 23.8% of Yearbook net supply	Treat loss reduction and network reinforcement as supply-equivalent options before assuming new generation is the only response.
Upstream deliverability	28 exploratory + 30 appraisal/development wells; 21 discoveries; oil 62,459 bbl/d; gas 2,890 MMcf/d	Measure exploration success by commercial reserves, development conversion and sustained production, not discovery counts alone.
Reserve/import nuance	Oil reserves ~240 MMbbl (down from ~243); gas reserves 23.31 Tcf (up from 18.47); oil import bill ~US$11.4bn and LNG ~US$3.37bn	Reserve additions can coexist with falling production; evaluate reserve replacement, deliverability and import/FX exposure together.

Source: HDIP (2026), Pakistan Energy Yearbook 2024-25. Derived interpretations and boundary checks follow the master synthesis and companion evidence database.

Boundary note: Yearbook T&D-loss definitions and later NEPRA loss metrics use different periods/system boundaries; they should not be merged without denominator reconciliation. Likewise, the oil-plus-LNG figures are not the complete national energy-import bill.

3. Global Comparator Lessons and Prospective Economics

The comparative strand begins with Khan, M. R. (2024), which contrasted Pakistan with India, China and the United States and asked how indigenous-resource choices affect import exposure and energy security. The present framework broadens that question. Countries are selected by the function or mechanism they demonstrate, not because their national energy mixes are directly transferable. The comparison is used to identify enabling conditions - resource development, technology, financing, grid architecture, flexibility, reservoir management, industrial scale or institutional capability - and then test whether those conditions can be reproduced under Pakistan-specific geology, water, infrastructure, demand and economics.

3.1 Why compare internationally: adaptation, not imitation

The policy value of comparison is not the headline percentage of coal, gas, hydro, wind or solar in another country. India is relevant as a large South Asian system with rapid demand growth, indigenous coal, hydropower and fast renewable expansion; China illustrates industrial scale, supply chains, coordinated transmission and multi-technology deployment; and the United States illustrates how technology-led resource development can alter the fuel balance. Specialized comparators then answer narrower questions: geothermal de-risking, high-VRE integration, dry-year management, direct heat and financing. The resulting policy test is “what problem was solved, what conditions made the solution work, and which of those conditions are transferable to Pakistan?”

Table 3.1: International comparator functions and the decision questions transferred to Pakistan.

Resource / system function	Comparator evidence	Transferable question for Pakistan economics
Macro resource transition / indigenous-resource productivity	India; China; United States	What can be learned from regional scale, domestic-resource use, technology-led supply shifts, transmission, industrial capability and diversification without copying national fuel shares?
Geothermal	Türkiye; Indonesia; Kenya; New Zealand; Iceland; United States	How exploration risk, reservoir confirmation, drilling, private/public finance, field management and direct heat affect EMV and DCF.
High-VRE systems	Denmark; China scale/supply-chain context	How grid capacity, markets, flexibility, curtailment and interconnection change delivered value.
Hydropower flexibility	Norway; New Zealand; Himalayan regional context	How reservoir state, seasonal inflow, dry-year risk and transmission affect firm value.
Bioenergy / sector coupling	Denmark plus Pakistan bagasse operating evidence	How feedstock, industrial steam, seasonality and utilization affect project economics.
Storage / grid services	International technology benchmarks + Pakistan ADB project case	How energy, reserve, congestion, reliability and curtailment value combine into a service stack.

Source basis: master synthesis comparator review, IEA country reviews, World Bank/ESMAP studies and cited peer-reviewed literature. Comparator cases are used for functions and enabling conditions, not as national fuel-share targets.

3.2 Initial comparator-derived Pakistan screening inputs

For renewable prospective cases, the economics workbook currently combines global 2024 installed-cost benchmarks with Pakistan screening capacity factors already used in the master synthesis. These are starting inputs for scenario analysis, not quoted Pakistan project prices.

Table 3.2: Comparator-derived benchmark inputs for prospective Pakistan screening cases.

Technology	Benchmark CAPEX (USD/kW)	Pakistan screening CF	Illustrative model size	Economic gate
Solar PV	691	22.8%	100 MW	Add site/grid, O&M and financing before full DCF.
Onshore wind	1,041	42.0%	100 MW	Add curtailment/evacuation and current financing.
Hydropower	2,267	45.0%	500 MW	Civil, hydrology, storage and grid must be site-specific.
Geothermal	4,015	88.0%	50 MW	Exploration-risk EMV precedes development DCF.
Bioenergy / bagasse	3,242	50.0%	30 MW	Feedstock/steam/seasonality must be project-specific.

Source: IRENA, Renewable Power Generation Costs in 2024, combined with Pakistan screening capacity-factor assumptions documented in the master synthesis. These are benchmark inputs, not quoted Pakistan project prices.

3.3 Scenario convention

The policy-support workbook uses three transparent scenario bands. Favourable/Best-Practice uses a 0.90 CAPEX multiplier, 1.05 capacity-factor multiplier, 0.90 O&M multiplier and 2-percentage-point lower debt/equity-return assumptions. Base/Realistic leaves benchmark conditions unchanged. Conservative/Stress uses a 1.25 CAPEX multiplier, 0.90 capacity-factor multiplier, 1.20 O&M multiplier and 3-percentage-point higher financing assumptions. These are modelling stresses, not forecasts or claims about future Pakistan procurement prices.

3.4 What the prospective envelopes quantify now

At the current evidence level, the strongest prospective result is a capital-and-energy screening envelope rather than a full project DCF. Applying the stated scenario multipliers to the benchmark-ready cases gives the ranges below. The base annual-energy values use the Pakistan screening capacity factors carried in the master synthesis; they do not include project-specific curtailment, outage, hydrology, feedstock or grid losses beyond the stated assumptions.

Table 3.3: Comparator-derived prospective capital and base-energy screening envelopes.

Technology / size	CAPEX envelope	Base CF	Base annual energy	Policy-use 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: master synthesis companion economics workbook. These are scenario envelopes, not project quotations, tariffs or DCF results.

3.5 Prototype bankability demonstration

The historical Safe Solar petition remains the only case in the current evidence set with Full-DCF evidence gate = Yes. In the final Brill-Viz run, the requested 5.48 USc/kWh tariff produces project NPV of about -US$0.246 million, project IRR 7.67%, equity IRR 8.38% against the 14% hurdle, minimum debt-year DSCR 0.863x and LCOE US$56.13/MWh. The equity-hurdle floor is US$66.99/MWh and the DSCR-constrained bankability floor is US$73.13/MWh (7.313 USc/kWh). A 5,000-iteration Monte Carlo gives P(NPV>0) of 37.7%, NPV P90/P50/Mean/P10 of about -US$1.89m/-US$0.414m/-US$0.317m/+US$1.42m, and LCOE P10/P50/Mean/P90 of US$52.19/57.01/57.24/62.59 per MWh. This remains a research prototype, not a current solar-market benchmark or investment conclusion.

3.6 Validated Brill-Viz project-screening outputs

The final report set adds representative full-life and point-forward screens without treating every calculated metric as decision-grade. The compact table below shows the outputs that are suitable for policy-facing use and the evidence boundary that must travel with them.

Table 3.4: Validated Brill-Viz project-screening outputs and policy-use boundaries.

Case / view	Selected result	Screening signal	Policy-use boundary
Safe Solar - full-life	NPV -US$0.246m; equity IRR 8.38%; LCOE US$56.13/MWh	DSCR floor US$73.13/MWh; P(NPV>0) 37.7%	Prototype only; Full-DCF gate Yes but not investment-grade.
Dawood wind - full-life	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/finance gaps.
Karot hydro - full-life	NPV -US$563.33m; IRR 7.72%; LCOE US$112.05/MWh	Floor US$140.53/MWh; P(NPV>0) 0%	Screening only; finance/current hydrology/tariff gaps.
Bhikki RLNG - full-life	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/finance/dispatch gaps.

Case / view	Selected result	Screening signal	Policy-use boundary
Pakistan geothermal - screen	NPV -US$78.75m; IRR 7.50%; LCOE US$108.06/MWh	Floor US$139.24/MWh; P(NPV>0) 0%	Comparator-derived; resource/drilling/offtake gate remains open.
Other gated cases	Engro/Almoiz calculated runs retained for audit; Nishat RFO is point-forward fuel/dispatch screen	Do not use zero-CAPEX/zero-O&M artefacts as project-return metrics	C-5 nuclear, ADB BESS and Chagai hybrid remain input-/system-value-gated.

Source: companion evidence database and Brill-Viz economics workbook, economics-validated revision, 18 September 2026. Outputs retain the evidence-use boundaries shown.

Note: historical/full-life construction years in the Brill-Viz reconstructions are normalized model years, not the projects' actual historical construction calendar. Point-forward screens do not re-spend sunk CAPEX and are not interpreted as project-return DCFs where current debt, tariff or O&M is missing.

4. Resource and Technology Decision Options

Table 4.1: Resource and technology decision options, economic conditions and remaining evidence gates.

Resource / intervention	What the evidence currently supports	Economic decision condition	Remaining evidence gate
Solar PV	Strong resource/deployment evidence and global cost benchmark	Compare new-build investor floor with site-specific grid/curtailment/land/cleaning-water value	Current project O&M/finance and delivered-grid-cost normalization by site.
Onshore wind	Measured resource, operating fleet and high-resource corridors	Compare delivered cost at grid-hosting sites; include curtailment and transmission	Current O&M/finance and site-specific evacuation.
Hydropower / pumped storage	Large indigenous hydro resource and operating portfolio	Separate annual-energy value from firm/flexible capacity and water opportunity cost	Chronological hydrology/reservoir data and site-specific PSH economics.
Geothermal / hydrothermal	Documented manifestations and global comparator mechanisms	Stage exploration risk first; development DCF only after flow/injectivity/reservoir evidence	Prospect-specific drilling cost, success probability, sustained flow, reinjection, grid/water design.
Nuclear	High operating utilization plus C-5 approved project evidence	Compare firm-energy value with financing, construction, water/cooling and evacuation	Project tariff, financing terms, O&M/fuel and C-5-specific water/evacuation.
Thar coal	Existing indigenous-security asset and observed operating economics	Compare existing/expansion cases on full delivered cost, utilization, water and environmental constraints	Current normalized mine/O&M/water/environment and project-specific financing.
RLNG CCGT	Efficient existing fleet with current fuel/tariff evidence	Test energy versus flexibility/capacity roles under fuel/FX and utilization scenarios	Actual current dispatch/fuel invoices and complete financing/O&M.
RFO / oil-fired	Operational residual fleet and strong current fuel-cost evidence	Evaluate remaining-life/flexibility value against high fuel/levy/FX exposure	Full current tariff/O&M/remaining-life finance and current dispatch/heat rate.
Bagasse / bioenergy	Operating cogeneration portfolio and project cost architecture	Use plant-specific feedstock, steam credit, seasonality and utilization	Current feedstock opportunity cost, O&M and recoverable national residue data.

Resource / intervention	What the evidence currently supports	Economic decision condition	Remaining evidence gate
Battery storage	Concrete Pakistan transmission-service proposal plus global performance benchmarks	Value service stack before LCOS/NPV; do not treat financing envelope as CAPEX	Total installed CAPEX, degradation/replacement and monetized service revenues.
Grid / transmission	Current TSEP and locational-constraint evidence	Compare network investment with avoided curtailment, congestion, fuel and reliability cost	Current nodal/hourly constraints and commissioning/outage chronology.
Efficiency / demand response	Demand/peak and institutional evidence	Compare cost of saved/shifted energy with avoided generation, fuel, capacity and network cost	Verified Pakistan cost curve and program-level realized savings.

5. Regional Decision Context

The master synthesis treats Pakistan as one interconnected portfolio, but resource and constraint conditions differ regionally. The table below is a screening emphasis, not a capacity allocation.

Table 5.1: Regional screening emphases and critical decision conditions for Pakistan.

Region	Screening emphasis from the synthesis	Critical decision conditions
Punjab	Load-centred solar; firm nuclear; agro-bioenergy; efficiency/grid; existing thermal flexibility	Demand density, land/interconnection, Chashma water/finance, bagasse utilization, RLNG fuel/FX.
Sindh	Wind-solar; grid/storage; coastal firm generation; industrial solar/bioenergy	Evacuation/curtailment, coastal grid, water, storage services, Thar full delivered economics.
Balochistan	Large solar-wind resource; local hybrids/storage; staged grid build-out; geothermal screening	Transmission distance, water scarcity, local demand/offtake, project scale and bankability.
Khyber Pakhtunkhwa	Hydropower; grid-loss reduction; solar/storage; geothermal direct-use screening	Hydrology, transmission, local reliability, pumped-storage site economics.
Gilgit-Baltistan	Local hydro; solar-storage; transmission planning; geothermal direct heat	Small-grid/offtake economics, EHV cost, winter energy, road/access and project scale.
Azad Jammu and Kashmir	Hydropower; solar-storage; pumped-storage screening; geothermal direct-use screening	Hydrology/reservoirs, evacuation, local resilience and bankability.

6. Cross-Cutting Economic Levers

6.1 Utilization and capacity-cost dilution

Observed FY2024-25 evidence shows that low utilization can materially raise procurement cost per delivered kWh when fixed/capacity obligations remain. Any new capacity case therefore needs a credible dispatch/utilization role, not only a technical availability assumption.

6.2 Fuel, FX and levy exposure

RLNG, RFO and imported coal require explicit commodity-price and exchange-rate stress. Imported equipment also creates FX exposure for renewable, nuclear, BESS and grid projects even where operating fuel exposure is low.

6.3 Financing cost

WACC, debt rate, tenor, grace period, indexation and currency denomination can materially change the investor floor. Comparator financing mechanisms can be tested as scenarios but are not automatically transferable.

6.4 Grid and locational value

Plant-level LCOE cannot represent congestion, curtailment, transmission reinforcement, reserve needs or avoided losses. The consumer/system ceiling is therefore location- and service-dependent.

6.5 Water and environmental constraints

Water can change the ranking of hydro, coal, nuclear, thermal cooling and some geothermal designs. Site-specific withdrawal/consumption and environmental compliance remain part of the project gate.

6.6 Uncertainty

P10/P50/Mean/P90 outputs are useful only when the underlying distributions are explicit. For cost metrics, the output must clearly identify which tail is low-cost/upside and which is high-cost/downside; for value metrics, the direction must likewise be labelled rather than inferred from the percentile name.

6.7 Efficiency and domestic resource productivity

The Yearbook evidence supports treating system efficiency and domestic-resource productivity as economic levers alongside new capacity. Network-loss reduction can avoid part of the need for additional delivered energy; industrial and commercial demand growth strengthens the value of reliable power quality; and upstream oil/gas policy should track reserve replacement, field redevelopment, recovery factor, development cycle time and sustainable deliverability together. Because reported gas reserves increased in FY2024-25 while gas production still declined, reserve growth should not be used as a substitute for production and infrastructure evidence. The same framework can test whether domestic resource gains actually reduce oil/LNG import and foreign-exchange exposure.

7. Decision Gates for Authorities and Project Sponsors

Table 7.1: Decision gates for authorities and project sponsors.

Gate	Question to resolve	Evidence required before stronger conclusions
Resource gate	Is the physical resource sufficiently proven?	Measured solar/wind; hydrology; geothermal flow/injectivity; feedstock; fuel supply.
Project-cost gate	Is the cost scope complete and current?	EPC, development, grid, land, water, contingency, IDC, replacements and decommissioning.
Financing gate	Is the capital structure realistic?	Debt/equity, currency, rate, tenor, grace, guarantees, tax and indexation.
Operating gate	Is utilization/dispatch credible?	Hourly/seasonal role, outages, fuel, hydrology, curtailment and service obligations.
System-value gate	What does the project avoid or enable?	Fuel imports, capacity, reliability, congestion, curtailment, network deferral, water/environment effects.
Bankability gate	Does investor floor fit inside system/consumer value?	DCF, DSCR, NPV/IRR, investor floor and defensible system ceiling.
Uncertainty gate	Does the conclusion survive stress?	P10/P50/Mean/P90 and explicit fuel/FX/CAPEX/financing/delay scenarios.

Gate	Question to resolve	Evidence required before stronger conclusions
Chronology gate	Is a portfolio/system claim being made?	Current 8,760 demand, unit dispatch/outages, hydro chronology, nodal limits, reserves/storage.

8. Monitoring and Accountability Metrics

Table 8.1: Monitoring and accountability metrics for energy-policy evaluation.

Dimension	Core KPI examples	Why it matters
Affordability	PKR/kWh system purchase cost; investor floor; tariff gap	Separates project bankability from consumer/system affordability.
Utilization	Capacity factor/utilization; availability; dispatch hours	Shows capacity-cost dilution and operational role.
Energy security	Imported-fuel share; FX sensitivity; domestic-resource share; reserve replacement; sustainable deliverability	Tracks exposure to commodity/currency shocks and whether domestic resource additions become usable supply.
Grid	Curtailment; congestion hours; losses; MW unlocked by transmission	Measures delivered value rather than busbar cost.
Reliability	Reserve margin; LOLE/EENS when chronology is available	Prevents low-cost energy from being confused with firm adequacy.
Water	Withdrawal/consumption m3/MWh; basin/site constraints	Captures regional water-energy trade-offs.
Finance	WACC; debt tenor; DSCR; NPV/IRR; construction delay	Shows whether financing structure changes the investor floor.
Evidence quality	Observed / sourced / derived / scenario classification	Keeps policy claims auditable and prevents assumptions becoming facts.

9. What This Paper Can and Cannot Establish

The current evidence is sufficient to compare operating-economic signals, establish a complete FY2024-25 annual energy baseline, identify major cost and import-exposure drivers, derive transferable lessons from international comparators, construct transparent comparator-derived scenarios, and apply validated Brill-Viz full-life/point-forward screening to representative projects. It is not sufficient to prove one unique national least-cost 2040/2050 mix or to convert screening outputs into investment advice because a complete primary current 8,760-hour demand, unit-dispatch/outage, hydrology and nodal-transfer dataset and several project-specific finance/contract inputs remain incomplete.

The integrated Yearbook and comparator evidence strengthens the descriptive basis for efficiency, indigenous-resource productivity and energy-security options, but it does not by itself prove causality or a preferred technology mix. Changes in sector consumption, drilling outcomes, reserves, production, imports, grid constraints and technology costs have different time lags and accounting boundaries. Policy appraisal can therefore test measurable decision conditions such as: lower delivered losses, productive utilization of existing assets, conversion of viable discoveries into sustainable domestic supply, transparent resource and project gates, and reduced exposure to imported-fuel price and foreign-exchange shocks where alternatives are technically and economically defensible.

The policy value of the current work is therefore its decision architecture: each technology, resource-development pathway or efficiency intervention can be tested on a consistent evidence chain, and missing inputs remain visible. The master synthesis retains the complete analytical record; the dual-view economics workbook provides reusable Brill-Viz inputs; and this paper provides the shorter authority-facing framework. International comparators contribute transferable mechanisms, while Brill-

Viz tests whether those mechanisms remain economically plausible under Pakistan-specific inputs. Screening results are retained with their evidence limits rather than being promoted to project-decision grade.

10. Strategic Policy Decision Areas from the Synthesis

The synthesis does not produce a technology ranking or a fixed national quota. It identifies a set of policy decision areas whose value depends on local evidence and explicit gates. The common objective is to improve resource productivity, reliability and affordability while reducing avoidable exposure to imported fuels, foreign exchange, water stress and under-utilized infrastructure.

10.1 Domestic hydrocarbons: exploration, deliverability and resource productivity

Oil and gas exploration, appraisal, field redevelopment and recovery improvement remain relevant to energy security because commercially deliverable domestic production can reduce import exposure. At the same time, reserve additions and discovery counts should be assessed together with development cycle time, sustained production and infrastructure. Diversification and efficiency can be tested for their ability to conserve scarce domestic hydrocarbons for uses where their economic and strategic value is higher.

10.2 Existing assets, networks and demand as energy-security resources

The FY2024-25 evidence supports evaluating loss reduction, transmission reinforcement, better dispatch, productive utilization of existing generation, demand efficiency and demand response alongside new supply. These measures can be compared with new generation on avoided energy, capacity, fuel, congestion and reliability value rather than treated as secondary measures.

10.3 Regionally differentiated portfolios

The national system can be evaluated as an integration of regional strengths and constraints rather than through one uniform technology mix. Solar, wind, hydro, nuclear, indigenous thermal resources, bioenergy, storage, geothermal prospects and demand-side measures have different values across regions because resource quality, water, demand density and grid access differ materially.

10.4 International learning as a decision input

The comparator outcome is a portfolio of lessons rather than a foreign template. India, China and the United States provide macro lessons on regional scale, indigenous resources, technology-led supply shifts and infrastructure; Kenya, Türkiye, Indonesia, Denmark, Norway, New Zealand and Iceland provide more specialized lessons on resource risk, financing, flexibility, hydrology and direct use. Each lesson enters policy analysis only after its enabling conditions and Pakistan-specific constraints are identified.

10.5 Operational meaning of sustainability and energy security

In this framework, sustainability means maintaining useful energy services over time without creating an unmanageable dependence on finite fuels, imported energy, water, infrastructure capacity or unaffordable finance. Energy security means maintaining those services through resource decline, fuel-price and FX shocks, hydrological variability, outages and network constraints. These definitions support transparent resilience tests rather than treating a single headline technology share as the security objective.

11. Research and Data Priorities for Next-Generation Economics

The largest remaining limitations are data-resolution limitations rather than missing technology categories. Closing the gaps below would allow the policy framework to move from comparative screening toward stronger chronological system analysis and project-level economics.

Table 11.1: Priority evidence gaps and the additional decision value they would provide.

Priority evidence gap	Additional decision value
Current 8,760-hour demand and regional/net-load series	Chronological adequacy, flexibility, storage and curtailment analysis.
Unit-level dispatch, outages, availability and fuel use	Actual operating role, capacity value and point-forward plant economics.
Hydro inflow, reservoir state and dispatch chronology	Firm hydro value, dry-year risk and pumped-storage screening.
Nodal transmission limits, losses, congestion and distributed-PV chronology	Locational generation/storage value and reconciliation of grid versus behind-the-meter supply.
Complete project CAPEX, O&M, financing, tariff/revenue and tax records	Upgrade Brill-Viz cases from screening/reconstruction to full project DCF.
Field-level oil/gas reserves, revisions, production decline and development timing	Reserve-replacement, brownfield productivity and commercial-deliverability analysis.
Geothermal temperature, permeability, flow, injectivity, chemistry and drilling cost	Move from prospectivity to exploration-risk EMV and bankable resource development.
Site-specific water use, demand-side cost curves and storage-service value	Compare water, efficiency, demand response and storage with supply-side investment on a common system-value basis.

The next-generation analytical objective is a linked evidence chain: resource evidence -> project economics -> chronological dispatch -> transmission and water constraints -> import/FX exposure -> consumer/system affordability. This would allow the Investor-Consumer Bankability Window to move from project screening toward a fuller system-planning application while preserving the distinction between observed evidence, derived calculations and scenarios.

12. Data Availability, Software and Declarations

12.1 Data availability and reproducibility

All quantitative results in this policy paper are derived from the master synthesis, public-source documents and the companion evidence database/economics workbook. Reported observations, derived calculations and scenario inputs are kept distinct, and public-source provenance is retained in the master source register. The underlying proprietary software code is not required to interpret the policy conclusions. A frozen supplementary data package containing the source register, table/figure inputs, principal scenario assumptions and representative analytical outputs can be deposited with a journal or public repository if required by the publication venue.

12.2 Software and analytical role

Brill-Viz was used for comparative analytics, cash-flow calculations, sensitivity and uncertainty analysis, and evidence-gated project screening. Brill-Viz is an analytical implementation tool rather than an independent evidence source. Source selection, assumptions, interpretation and policy framing remain the responsibility of the author.

12.3 Funding and competing interests

No external funding source is identified in the master synthesis or this policy paper. The author operates enerbrill and is the developer of Brill-Viz; this relationship is disclosed because Brill-Viz is used as an analytical tool in the study. No policy claim is treated as validated merely because it is generated by Brill-Viz; each result remains subject to the evidence gates and source boundaries stated in the paper.

12.4 Editorial and generative-AI assistance

Generative-AI tools were used for editorial, drafting and document-development support under author supervision. Source selection, data checks, calculations, scientific interpretation, policy framing and final responsibility for the paper remain with the author. The wording of this disclosure should be adapted, if necessary, to the specific requirements of the target journal or publisher.

13. 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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