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Original Research Article

Strategic Financing of Energy Efficiency Solutions in Saudi Arabia's Power Generation Sector: An Investment Framework for Vision 2030

Muhammad Anas[1]*
[1]Independent Researcher

***Corresponding Author**
Muhammad Anas
Independent Researcher

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Abstract: Saudi Arabia's electricity system is undergoing a capital-intensive transition, in which efficiency improvements at existing and new generating assets must compete for funding with renewables, grids, storage, and gas infrastructure. This review explores how financing design is able to transform technically credible energy-efficiency opportunities in power generation into investable projects aligned with Vision 2030. Rather than viewing efficiency solely as an engineering issue, the paper integrates evidence on heat-rate improvement, combined-cycle optimisation, digital operation and maintenance, auxiliary-load reduction, flexible generation, energy-performance contracting, green bonds, sukuk, and blended finance. A structured review of peer-reviewed literature from 2020 to 2025 links technical savings to risk allocation, cash-flow certainty, and cost of capital. The findings show that financing quality significantly affects the bankability of efficiency projects, as verified savings are often distributed across fuel, maintenance, reliability, and capacity benefits rather than consolidated in a single revenue stream. In Saudi Arabia, the most compelling near-term approach is to aggregate repeatable efficiency measures across generation portfolios, apply transparent baselines and performance guarantees, and connect refinancing to verified outcomes. The review concludes that energy efficiency should be considered productive infrastructure: a financing category that can reduce system costs, support renewable integration, conserve fuels, and improve the credibility of transition investments under Vision 2030.

Keywords: Energy Efficiency; Power Generation; Project Finance; Green Bonds; Sukuk; Blended Finance; Energy-Performance Contracting.

1. INTRODUCTION

Saudi Arabia's power sector is being restructured by two main imperatives: rapidly expanding cleaner supply and making more productive use of existing fuel, capacity, and capital. Vision 2030 has accelerated renewable-energy procurement and broader energy-sector restructuring, yet the system still relies heavily on thermal generation. The transition entails more than building solar and wind plants; it also requires investment in the efficiency, flexibility, and dependability of existing and replacement assets to integrate variable renewables without incurring excess fuel, operating, or reserve costs. Reviews of the Saudi transition regularly emphasize technology, grid readiness, infrastructure, and investment as interdependent constraints instead of isolated issues

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(Amran *et al*., 2020; Al Zohbi and AlAmri, 2020; Ali *et al*., 2021; Elshurafa *et al*., 2021; Rahman *et al*., 2022; Ali, 2023). Energy efficiency in power generation has a distinctive financial character. A new renewable plant usually produces a metered output sold under an identifiable commercial arrangement. An efficiency retrofit, by contrast, creates value through avoided inputs and improved operating performance. A compressor upgrade may lower auxiliary consumption; turbine refurbishment may reduce heat rate; advanced controls can improve dispatch efficiency; predictive maintenance can reduce forced outages; and flexible operation can lower cycling penalties. These gains are economically real, yet investors may struggle to lend against them because the counterfactual is not directly observable. The project must demonstrate what fuel consumption, maintenance expense or availability would have been without the intervention. This measurement problem connects engineering design to contract design and ultimately to financing cost. This review addresses that intersection. It asks how a Saudi power producer, utility, public investment entity or financing institution could move from a list of technical efficiency measures to a portfolio that is credible to credit committees and consistent with national transition priorities. The paper does not estimate a new plant-level econometric model. Instead, it synthesises recent evidence to build a practical investment framework. The contribution is threefold: it distinguishes the cash-flow logic of supply-side efficiency from conventional generation investment; it maps financing instruments to project characteristics and risk profiles; and it proposes a staged framework that links technical verification, contractual allocation and capital structure to Vision 2030 outcomes.

2. Aim and Objectives of the Review

This study develops an investment-oriented framework for financing energy-efficiency solutions in Saudi Arabia's power generation sector by integrating technical performance, risk allocation and sustainable-finance evidence published between 2020 and 2025. The emphasis is on the financing architecture required to make efficiency measures bankable at plant and portfolio level. Four objectives guide the review. First, it identifies generation-side energy-efficiency investments that can create measurable economic value in a transitioning Saudi electricity system. Second, it evaluates financial frictions that can prevent technically attractive measures from receiving capital, including baseline uncertainty, fragmented project size, technology risk, fuel-price exposure, contracting complexity and the absence of dedicated revenue streams. Third, it compares balance-sheet funding, project debt, energy-performance contracts, green bonds, green sukuk and blended finance against the risk and cash-flow profile of efficiency projects. Fourth, it synthesises the findings into a decision framework for screening, structuring, financing, monitoring and refinancing investments while maintaining alignment with Vision 2030, energy security and emissions objectives.

3. REVIEW METHODOLOGY

A structured integrative review was selected because the research question spans engineering performance, energy economics, project finance and sustainable-finance instruments. Restricting the review to one discipline could omit material evidence on financing or power systems, while a purely narrative review without explicit selection rules would weaken transparency. The approach combines defined search and screening criteria with thematic synthesis suitable for investment-framework analysis. The review window was restricted to 2020–2025 to reflect rapid changes in renewable costs, sustainable-finance markets and Saudi energy policy. Search concepts were organised into four groups: Saudi Arabia and Vision 2030; power generation and energy efficiency; investment, cost of capital and project finance; and green finance, bonds, sukuk or blended finance. Priority was given to peer-reviewed publications with a DOI, and the final reference set was limited to thirty sources. Saudi-specific studies established the national power and investment context, while international studies were retained when they provided transferable evidence on financing barriers, cost of capital, energy-performance contracts, measurement problems or green financial instruments. The synthesis followed three stages. First, each study was coded by its principal decision variable: technical value, cash-flow formation, risk, financing mechanism, or policy and governance. Second, findings were compared for agreement and relevance to a thermal and increasingly hybrid Saudi power system. Evidence from building efficiency, European auctions and Chinese green-finance programmes was used only to illustrate mechanisms such as information asymmetry, cost-of-capital sensitivity and risk mitigation rather than as direct analogues to Saudi projects. Third, these mechanisms were assembled into an investment sequence from technical screening to monitoring and refinancing. The method therefore builds a reasoned framework from convergent evidence while distinguishing Saudi-specific findings from general financing principles.

Quality control emphasised publication status, DOI validity, methodological clarity and relevance to the review question. Descriptive reports without a DOI were excluded from the thirty-item reference list, even when useful for policy context. This improves traceability but limits coverage of some current Saudi programme details that are better documented in government or industry sources. Accordingly, the framework is an academic investment synthesis rather than a substitute for transaction-level due diligence or current regulatory guidance.

4. Energy-Efficiency Value in Saudi Power Generation

Generation-side efficiency creates value through reducing the resources required to deliver dependable electricity. For gas-fired and liquid-fuel units, heat-rate improvement is the most direct channel because a lower heat rate reduces fuel consumed per unit of electricity. Additional value can arise from reduced auxiliary loads, better condenser performance, advanced combustion control, inlet-air optimisation, improved steam-cycle integration and refurbishment of ageing components. Digital surveillance and predictive maintenance can complement these measures by reducing degradation, shortening outages and helping operators preserve performance closer to design conditions. The result is not simply lower energy use. It can also be higher availability, lower maintenance volatility and improved dispatch flexibility. These benefits matter more in a system with rising variable renewable penetration. Saudi studies show that the transition entails simultaneous decisions about renewable deployment, thermal capacity, network requirements and emissions (Elshurafa *et al*., 2021; Riera *et al*., 2022; Al-Shetwi, 2022; Di Lorenzo *et al*., 2024; Alghamdi *et al*., 2025). Efficient thermal assets can support this transition when they operate flexibly and economically during periods in which solar or wind output changes. However, efficiency projects should not be used to justify preserving inefficient capacity indefinitely. Investment screening must consider expected utilisation, retirement pathways, fuel policy and the probability that a retrofit becomes stranded before recovering its capital cost. This is why the technical business case must be integrated with an asset-transition case. Saudi renewable research also demonstrates that investment decisions are sensitive to multiple criteria rather than a single measure of financial return. Scenario analysis merges economic, environmental, social and risk dimensions, while more recent work underlines the importance of financing conditions and private investment in achieving national targets (Kerrouche and Zehri, 2024). For efficiency projects, the equivalent logic is to evaluate fuel savings alongside reliability, emissions, flexibility, and system value. A retrofit that produces a modest direct fuel saving but substantially reduces forced outages at a strategically located plant may have greater economic value than a project with a shorter simple payback but little system benefit. The investment problem is therefore one of monetisation. Fuel savings can be valued using an agreed reference fuel price or transfer price. Maintenance savings can be estimated from historical work orders and failure rates. Reliability gains can be translated into avoided outage costs, additional saleable generation or reduced reserve requirements where contractual arrangements permit. Emission reductions can support green-finance eligibility, although they should not be counted as cash unless a credible market or incentive exists. Flexibility benefits are particularly difficult because they depend on dispatch rules and system conditions. The framework proposed in this review therefore separates core contracted cash flows from strategic co-benefits. Debt sizing should rely primarily on savings and revenues that can be measured and enforced. At the same time, policy and ESG benefits can strengthen eligibility, pricing or investor demand without being treated as guaranteed income.

Table 1: Mapping of generation-efficiency opportunities to underwriting evidence and financing routes

Efficiency opportunity	Primary value mechanism	Key underwriting evidence	Suitable financing route
Heat-rate / turbine upgrade	Fuel savings and lower variable cost	Pre/post heat-rate test; operating profile; OEM guarantee	Corporate debt; limited-recourse facility
Auxiliary-load reduction	Lower internal electricity consumption	Metered auxiliary baseline and verified load reduction	Corporate facility; ESCO contract
Digital optimisation / predictive O&M	Availability, reduced degradation and maintenance volatility	Historical outages; algorithm governance; service-level guarantee	Performance contract; blended pilot finance
Flexibility retrofit	Lower cycling cost and better renewable integration	Dispatch scenarios; start cost; ramp performance	Corporate / transition finance
Portfolio of repeatable measures	Diversified savings and scale economies	Common M&V protocol; pooled performance history	Green sukuk/bond refinancing; revolving facility

5. Why Efficient Projects Can Remain Unfunded

The central paradox of energy-efficiency finance is that a project may show a positive net present value and still fail to attract capital. Evidence on the efficiency gap identifies several explanations. Information asymmetry can make lenders uncertain about the quality of equipment, contractors or predicted savings. Managers may apply hurdle rates far above the firm's normal cost of capital because efficiency projects compete with core production investments. Small project size raises transaction costs, while uncertain future energy prices reduce confidence in savings. Policy uncertainty can delay decisions even where technologies are mature (Giraudet, 2020; Park *et al*., 2022; Bremer *et al*., 2024). These mechanisms are highly relevant to power-generation retrofits because savings depend on operating profiles and technical baselines that are not always transparent outside the plant. A second barrier is the difference between accounting payback and financeable cash flow. Internal engineering teams may justify a project using avoided fuel expenditure, but a lender requires evidence that those savings will remain available for debt service. If the plant owner is not the party paying for fuel, or if tariffs and dispatch rules socialise the savings, the project sponsor may lack a direct revenue incentive. Likewise, improved availability has value only if the plant can monetise additional output or evade penalties. Finance ability therefore depends as much on institutional arrangements as on technical performance. Third, efficiency projects can be fragmented. A portfolio may contain dozens of measures with different equipment vendors, implementation dates and savings profiles. Individually, each project may be too small for project finance; collectively, they may be large enough but difficult to standardise. Portfolio aggregation solves this problem by creating common eligibility criteria, standard measurement and verification rules, and a repeatable contracting package. The resulting pool can support a revolving facility or refinancing instrument after performance is demonstrated. International research on energy-efficiency decision tools supports the value of systematic project screening and comparable metrics in reducing information and transaction costs (Karakosta *et al*., 2021; Sarmas *et al*., 2022).

Finally, the financing environment matters. Renewable-energy research shows that cost of capital is not a passive input but a determinant of levelised cost and investment feasibility (Steffen, 2020). Revenue certainty, counterparty strength and policy credibility can lower financing costs, while country, technology and market risks increase them (Breitschopf and Alexander-Haw, 2022; Gohdes *et al*., 2022). Efficiency projects face an analogous issue: a guaranteed and independently verified savings stream can be financed more cheaply than an unverified engineering estimate. The investment framework should therefore treat de-risking as an economic intervention. Better baselines, guarantees, insurance, reserve accounts and credible counterparties can create worth by lowering required returns, not simply by protecting investors after problems arise.

6. Financing Methods and Their Strategic Fit

Balance-sheet finance is the simplest mechanism for large utilities and financially strong generation companies. The owner funds the retrofit through retained earnings or corporate borrowing and retains all savings. This approach minimises transaction complexity and suits measures that are vital to plant maintenance or have short implementation periods. Its limitation is capital competition: even attractive efficiency projects can be deferred when corporate borrowing capacity is reserved for new generation, networks or acquisitions. A dedicated internal capital-allocation rule for verified efficiency can reduce this bias. Project finance can be appropriate when a retrofit or portfolio produces ring-fenced cash flows and has sufficient scale. The principle is familiar from renewable projects, where debt and equity depend on project cash flows and the cost of capital responds strongly to revenue quality (Steffen, 2020; Gohdes *et al*., 2022). For generation efficiency, pure non-recourse structures may be difficult because savings are embedded in the host plant. A more realistic approach is limited-recourse financing supported by a contractual savings payment, availability payment or service fee from a creditworthy plant owner. Energy-performance contracting directly addresses performance uncertainty. An energy service company can design, finance or implement measures and receive payment from verified savings. Carbon-linked and performance-based financing models show how contractual design can expand funding options for efficiency projects (Shang *et al*., 2020). For Saudi generation assets, an EPC-style model would need meticulous adaptation because complex turbines and balance-of-plant systems involve operational decisions outside the contractor's control. The contract should define baseline conditions, dispatch adjustments, degradation factors and exceptional events so that the ESCO is not rewarded or penalised for changes unrelated to its intervention. Green bonds and green sukuk are best viewed as refinancing and aggregation tools rather than automatic substitutes for project economics. Evidence indicates that green-bond development can support renewable investment and energy efficiency, although effects vary by market and period (Ning *et al*., 2023; Chang *et al*., 2023; Zhang *et al*., 2023; Zhao *et al*., 2023). A labelled instrument does not make weak savings bankable; it can broaden the investor base and improve financing terms when proceeds are linked to eligible assets, open reporting, and credible verification. Blended finance can be justified where projects have high strategic value but face risks that private capital prices too heavily. A concessional tranche, guarantee or first-loss facility can absorb technology, demonstration or aggregation risk and crowd in commercial lenders. The objective should be to address a defined market failure, not to subsidise ordinary operating expenditure. Islamic blended-finance research illustrates how layered capital can shorten the path from pilot projects to scaled renewable investment (Mukhtasor *et al*., 2023). In Saudi power efficiency, blended structures may be most useful for first-of-a-kind digital optimisation, advanced retrofits with uncertain performance, or pooled programmes involving multiple plants and contractors.

7. Sustainable Finance, Cost of Capital and Bankability

Sustainable finance improves project economics when it changes the quantity, maturity or price of capital available to credible projects. Empirical research increasingly links green finance with energy-efficiency improvement, renewable investment and cleaner energy structures (Li *et al*., 2021; Liu *et al*., 2023; Lee *et al*., 2023; Al-Kasasbeh *et al*., 2024). However, the causal channels matter. A green label can reduce information search costs and attract specialised investors. Still, the most durable reduction in financing cost comes from stronger project fundamentals: transparent data, stable contracts, credible counterparties and enforceable rights.

Cost-of-capital research provides a useful discipline for evaluating Saudi efficiency financing. Renewable projects are capital intensive, so even small differences in discount rates materially affect levelised costs and bid prices. Empirical work finds substantial variation by country, technology and risk allocation, while auction-based estimates show that financing conditions can be inferred from competitive outcomes (Steffen, 2020). Generation-efficiency projects are often less capital intensive than new renewables but can still be highly sensitive to financing terms when savings accrue slowly over the remaining asset life. A high hurdle rate can eliminate projects that would be attractive under lower-risk, longer-tenor financing. Bankability therefore requires the project to transform uncertain engineering gains into a hierarchy of cash-flow evidence. At the first level are directly measurable savings such as reduced fuel or electricity consumed by auxiliary equipment. At the second level are operational savings such as lower maintenance or fewer forced outages, which require historical benchmarks. At the third level are system and environmental benefits whose monetisation may depend on market reform, policy incentives or internal carbon values. Debt service should be calibrated to the first and strongest part of the second level. Equity investors and public sponsors can take exposure to the more strategic benefits. Green-bond studies provide additional lessons. The implication is that Saudi issuers should avoid assuming a fixed greenium. The financing advantage of a green bond or sukuk should be assessed transaction by transaction against conventional debt after accounting for verification, reporting and structuring costs. The strongest case appears when efficiency assets are already producing verified savings and can be aggregated into a sufficiently large refinancing pool.

8. Proposed Investment Framework for Vision 2030

The proposed framework consists of five sequential gates. Gate one is technical screening. Each candidate measure is assessed for expected energy saving, implementation cost, outage requirements, remaining asset life, operational dependencies and contribution to flexibility plus reliability. Measures that merely defer unavoidable maintenance are separated from genuine efficiency improvements. A standard baseline is defined before procurement so that later financing decisions are based on comparable data. Gate two is cash-flow translation. Engineering savings are converted into financial benefits using transparent assumptions for fuel value, auxiliary electricity, maintenance, availability as well as any contractual penalties or incentives. Sensitivity analysis is applied to utilisation, fuel prices and degradation. This step is critical because a project with a strong simple payback can become weak under a realistic dispatch profile. The cash-flow model should identify a conservative debt-service case, an expected equity case and calculated co-benefits that are not relied upon for repayment. Gate three is risk allocation. Measurement and verification rules specify metering, baseline adjustments, data ownership and dispute resolution. Where performance guarantees exist, the guarantee should be sized to the economic exposure rather than expressed only as a technical efficiency percentage.

Gate four is capital-structure selection. Short-payback measures at strong corporate owners are funded on the balance sheet. Larger ring-fenced programmes can use senior debt supported by a savings or service agreement. Performance contracts are favoured where technical uncertainty is material and a capable ESCO can assume it. Green bonds or green sukuk are used when a portfolio is large enough to justify labelled issuance and reporting. Blended finance is reserved for demonstrable market failures, innovation risk or programmes with planned system benefits that are not yet fully monetised. This matching principle prevents the financing instrument from steering project selection. Gate five is governance and refinancing. Post-implementation performance is independently verified and compared with the approved baseline. Underperforming measures trigger contractual remedies or operating reviews. Successful projects enter a verified asset pool that can support refinancing, releasing sponsor capital for the next investment cycle. Over time, this creates a data history of Saudi generation-efficiency performance. Such a database can reduce uncertainty, boost future underwriting and allow lenders to price efficiency risk based on evidence rather than generic corporate assumptions. The framework is consistent with Vision 2030 because it treats efficiency as a complement to renewable expansion and power-system modernisation. Financing effectiveness within this wider portfolio can conserve fuel, reduce emissions, lower operating costs and improve the flexibility required to integrate renewables. The central principle is additionality: finance should prioritise measures that generate verifiable improvements beyond normal maintenance and that remain economically useful under plausible transition scenarios.

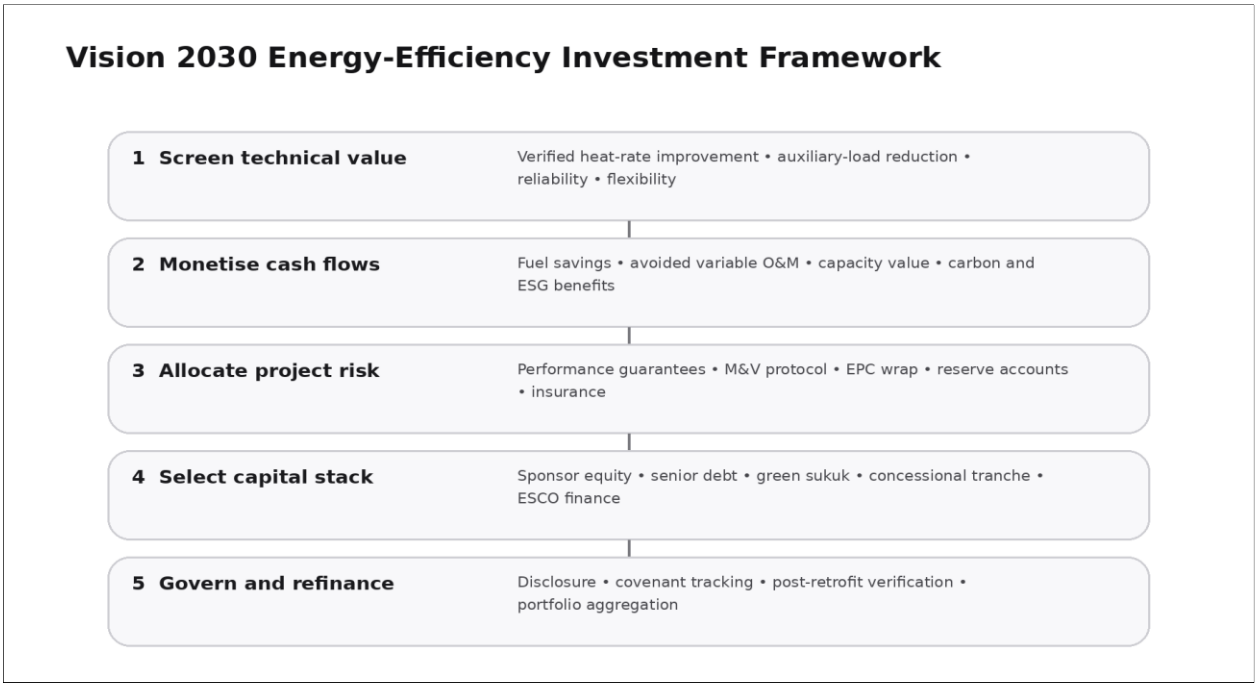

Figure 2: Five-gate investment framework for Saudi power-generation energy efficiency

Table 2: Risk allocation matrix for bankable energy-efficiency investment

Risk	How it affects bankability	Preferred allocation / mitigation	Financing implication
Baseline and savings risk	Weakens confidence in debt-service coverage	Independent M&V; conservative baseline; adjustment rules	Lower leverage until verified
Technology / performance risk	Creates cost overrun or savings shortfall	OEM/ESCO guarantee; insurance; reserve	Performance-linked pricing
Dispatch and utilisation risk	Reduces realised fuel saving	Scenario analysis; minimum service payment where justified	Shorter tenor or lower debt sizing
Fuel-price risk	Changes value of avoided fuel	Reference price formula; sensitivity bands	Covenant headroom
Counterparty risk	Threatens payment of service or savings fee	Credit support; escrow; strong obligor	Determines debt pricing
Policy / taxonomy risk	May affect green eligibility or market treatment	Clear eligibility rules; transition criteria; disclosure	Influences labelled-finance demand

9. DISCUSSION

The review suggests that the most important innovation is not a single financing product but a change in how energy efficiency is packaged. Traditional engineering appraisal asks whether a retrofit saves enough fuel to recover its cost. This shift explains why apparently attractive efficiency opportunities can remain unfunded and why standardisation has strategic value. For Saudi Arabia, portfolio aggregation is especially promising. Large generation owners can identify common measures across fleets, standardise technical specifications and create a unified measurement protocol. A portfolio approach diversifies plant-specific performance risk and creates financing scale. It also spreads procurement, verification, and legal costs across multiple investments. After a performance history is established, the portfolio can be refinanced through bank facilities, institutional debt or a labelled sukuk. This sequencing is preferable to issuing a green instrument first and then searching for eligible projects. The framework also clarifies the role of public policy. Government support is most effective where it reduces risks that private parties cannot efficiently manage. Examples include standardised measurement procedures, transparent fuel and market rules, credit enhancement for demonstration portfolios, taxonomic clarity for eligible efficiency expenditure and public disclosure of verified programme outcomes. Evidence on green finance indicates that financial development can improve energy efficiency through technology innovation and energy-structure change, while uncertainty can weaken investment response (Lee *et al.*, 2023; Bremer *et al.,* 2024). Policy should therefore aim to improve information quality and predictability rather than rely solely on subsidies. There are boundaries to the argument. Energy efficiency is not automatically green if it extends the life of high-emission assets without supporting a credible transition pathway. A retrofit should be assessed against expected utilisation, retirement timing and alternative investment. Likewise, reduced fuel use at one plant does not guarantee system-wide emission reductions if cheaper operation causes significantly higher dispatch. Portfolio governance should therefore include system-level indicators and avoid double counting savings that arise from broader dispatch or fuel-switching changes. The evidence base also has methodological drawbacks. Much of the green-finance literature is based on national or regional panel data, making direct transfer to project-level Saudi power assets uncertain. Studies of building efficiency reveal important financing mechanisms but involve different operating and contractual conditions (Al-Homoud and Krarti, 2021). Saudi-specific research is more robust on renewable deployment and system transition than on financing of generation-efficiency retrofits. These gaps support a future research agenda based on debt pricing, contract performance and refinancing outcomes.

10. Policy and Managerial Implications

For decision makers, verified energy savings must be legible to financial markets. A Saudi generation-efficiency measurement and verification protocol should define accepted baselines, treatment of dispatch changes, weather adjustments, outage periods and degradation. Standard rules would lower due-diligence costs and improve comparability across plants. A taxonomy should distinguish routine maintenance from incremental efficiency expenditure and clarify when thermal-asset improvements qualify for green or transition finance.

Generation companies should use risk-adjusted financing rather than simple payback alone. Projects with stable savings and low technical risk may justify lower hurdle rates than experimental upgrades. Investment committees should value reliability and flexibility while keeping these co-benefits separate from contracted debt-service cash flows. Banks and institutional investors should require transparent baselines, independent verification, sensitivity analysis and clear remedies for underperformance. Once operating history is sufficient, portfolios can be refinanced at longer tenors, with green bonds or sukuk recycling capital from seasoned efficiency assets.

ESCOs and technology suppliers create value through credible risk assumption. Performance guarantees require adequate balance-sheet strength, insurance or reserve support and should exclude operating conditions outside the provider's control. Digital monitoring can provide continuous performance evidence, although data validity and cybersecurity then become financing concerns. Public and private actors should develop repeatable pipelines so projects pass through common gates, performance data accumulate and successful assets can be refinanced efficiently.

11. CONCLUSION

Strategic financing can turn power-generation energy efficiency from a collection of engineering opportunities into a scalable investment class. The review shows that the decisive issue is not whether efficiency produces value, but whether that value is measurable, contractible and allocated to parties able to finance and manage the associated risks. Saudi Arabia's transition creates a strong rationale for such investment because efficient, flexible generation can conserve fuel, reduce operating costs, improve reliability, and support renewable integration during a period of rapid system change.

The proposed framework links five decisions: technical screening, cash-flow translation, risk allocation, capital-structure selection, and performance governance with refinancing. Across all instruments, measurement and verification underpin bankability. The review further argues that Vision 2030 alignment should be shown by additional and persistent system benefits rather than assumed from an efficiency label. Projects should stay valuable under realistic dispatch and asset-life scenarios, and financing should not create incentives to prolong inefficient capacity unnecessarily. A national portfolio approach, supported by standard baselines and open reporting, could create the performance evidence required to lower future financing costs. In this sense, energy efficiency is best understood as productive infrastructure: investment that improves the output of existing capital while strengthening the economics and resilience of the wider Saudi power transition.

REFERENCES

- Al Zohbi, G. and AlAmri, F.G. (2020) 'Current situation of renewable energy in Saudi Arabia: Opportunities and challenges', Journal of Sustainable Development, 13(2), pp. 98–119. https://doi.org/10.5539/jsd.v13n2p98.
- Alghamdi, N., James, P. and Bahaj, A. (2025) 'Vision and reality: An assessment of Saudi Arabia's in-country capacity to deliver on its solar ambitions', Sustainability, 17(13), 5721. https://doi.org/10.3390/su17135721.
- Al-Homoud, M.S. and Krarti, M. (2021) 'Energy efficiency of residential buildings in the Kingdom of Saudi Arabia: Review of status and future roadmap', Journal of Building Engineering, 36, 102143. https://doi.org/10.1016/j.jobe.2020.102143.
- Ali, A. (2023) 'Transforming Saudi Arabia's energy landscape towards a sustainable future: Progress of solar photovoltaic energy deployment', Sustainability, 15(10), 8420. https://doi.org/10.3390/su15108420.
- Ali, A., Alsulaiman, F.A., Irshad, K., Shafiullah, M., Malik, S.A. and Memon, A.H. (2021) 'Renewable portfolio standard from the perspective of policy network theory for Saudi Arabia Vision 2030 targets', 2021 4th International Conference on Energy Conservation and Efficiency (ICECE), pp. 1–6. https://doi.org/10.1109/ICECE51984.2021.9406286.
- Al-Kasasbeh, O., Al-Khazaleh, S.M. and Alsheikh, G. (2024) 'The dynamic impact of environmental sustainability, green finance, and FinTech on energy efficiency in Middle Eastern economies', International Journal of Energy Economics and Policy, 14(4), pp. 574–579. https://doi.org/10.32479/ijeep.15691.
- Al-Shetwi, A.Q. (2022) 'Sustainable development of renewable energy integrated power sector: Trends, environmental impacts, and recent challenges', Science of the Total Environment, 822, 153645. https://doi.org/10.1016/j.scitotenv.2022.153645.
- Amran, Y.H.A., Amran, Y.H.M., Alyousef, R. and Alabduljabbar, H. (2020) 'Renewable and sustainable energy production in Saudi Arabia according to Saudi Vision 2030: Current status and future prospects', Journal of Cleaner Production, 247, 119602. https://doi.org/10.1016/j.jclepro.2019.119602.
- Breitschopf, B. and Alexander-Haw, A. (2022) 'Auctions, risk and the WACC: How auctions and other risk factors impact renewable electricity financing costs', Energy Strategy Reviews, 44, 100983. https://doi.org/10.1016/j.esr.2022.100983.
- Bremer, L., den Nijs, S. and de Groot, H.L.F. (2024) 'The energy efficiency gap and barriers to investments: Evidence from a firm survey in the Netherlands', Energy Economics, 133, 107498. https://doi.org/10.1016/j.eneco.2024.107498.
- Chang, L., Moldir, M., Zhang, Y. and Nazar, R. (2023) 'Asymmetric impact of green bonds on energy efficiency: Fresh evidence from quantile estimation', Utilities Policy, 80, 101474. https://doi.org/10.1016/j.jup.2022.101474.

- Di Lorenzo, G., Stracqualursi, E., Vescio, G. and Araneo, R. (2024) 'State of the art of renewable sources potentialities in the Middle East: A case study in the Kingdom of Saudi Arabia', Energies, 17(8), 1816. https://doi.org/10.3390/en17081816.
- Elshurafa, A.M., Alatawi, H., Soummane, S. and Felder, F.A. (2021) 'Assessing effects of renewable deployment on emissions in the Saudi power sector until 2040 using integer optimization', The Electricity Journal, 34(6), 106973. https://doi.org/10.1016/j.tej.2021.106973.
- Giraudet, L.-G. (2020) 'Energy efficiency as a credence good: A review of informational barriers to energy savings in the building sector', Energy Economics, 87, 104698. https://doi.org/10.1016/j.eneco.2020.104698.
- Gohdes, N., Simshauser, P. and Wilson, C. (2022) 'Renewable entry costs, project finance and the role of revenue quality in Australia's National Electricity Market', Energy Economics, 113, 106312. https://doi.org/10.1016/j.eneco.2022.106312.
- Karakosta, C., Mylona, Z., Karásek, J., Papapostolou, A. and Geiseler, E. (2021) 'Tackling COVID-19 crisis through energy efficiency investments: Decision support tools for economic recovery', Energy Strategy Reviews, 38, 100764. https://doi.org/10.1016/j.esr.2021.100764.
- Kerrouche, N. and Zehri, C. (2024) 'The economic effects of renewable energy investments: Evidence from firm-level data', International Journal of Energy Economics and Policy, 14(5), pp. 220–228. https://doi.org/10.32479/ijeep.16539.
- Lee, C.-C., Wang, C.-S., He, Z., Xing, W.-W. and Wang, K. (2023) 'How does green finance affect energy efficiency? The role of green technology innovation and energy structure', Renewable Energy, 219, 119417. https://doi.org/10.1016/j.renene.2023.119417.
- Li, M., Hamawandy, N.M., Wahid, F., Rjoub, H. and Bao, Z. (2021) 'Renewable energy resources investment and green finance: Evidence from China', Resources Policy, 74, 102402. https://doi.org/10.1016/j.resourpol.2021.102402.
- Liu, Z., Xu, J., Wei, Y., Abu Hatab, A. and Lan, J. (2023) 'Nexus between green financing, renewable energy generation, and energy efficiency: Empirical insights through DEA technique', Environmental Science and Pollution Research, 30(22), pp. 61290–61303. https://doi.org/10.1007/s11356-021-17092-3.
- Mukhtasor, M., Listiana, L., Hermala, I. and Nur Fauziah, N. (2023) 'Scaling up renewable energy financing through Islamic blended finance: Case study in Indonesia', International Journal of Energy Economics and Policy, 13(5), pp. 634–644. https://doi.org/10.32479/ijeep.14710.
- Ning, Y., Cherian, J., Sial, M.S., Álvarez-Otero, S., Comite, U. and Zia-Ud-Din, M. (2023) 'Green bond as a new determinant of sustainable green financing, energy efficiency investment, and economic growth: A global perspective', Environmental Science and Pollution Research, 30(22), pp. 61324–61339. https://doi.org/10.1007/s11356-021-18454-7.
- Park, J., Woo, J.R. and Jin, T. (2022) 'Estimating implicit discount rate for energy efficiency investment using the contingent valuation method: A case study in South Korea', Energy Efficiency, 15, 67. https://doi.org/10.1007/s12053-022-10076-3.
- Rahman, M.M., Hasan, M.A., Shafiullah, M., Rahman, M.S., Arifuzzaman, M., Islam, M.K., Islam, M.M. and Rahman, S.M. (2022) 'A critical, temporal analysis of Saudi Arabia's initiatives for greenhouse gas emissions reduction in the energy sector', Sustainability, 14(19), 12651. https://doi.org/10.3390/su141912651.
- Riera, J.A., Lima, R.M., Hoteit, I. and Knio, O. (2022) 'Simulated co-optimization of renewable energy and desalination systems in Neom, Saudi Arabia', Nature Communications, 13, 3514. https://doi.org/10.1038/s41467-022-31233-3.
- Sarmas, E., Marinakis, V. and Doukas, H. (2022) 'A data-driven multicriteria decision making tool for assessing investments in energy efficiency', Operational Research, 22, pp. 5597–5616. https://doi.org/10.1007/s12351-022-00727-9.
- Shang, T., Yang, L., Liu, P., Shang, K. and Zhang, Y. (2020) 'Financing mode of energy performance contracting projects with carbon emissions reduction potential and carbon emissions ratings', Energy Policy, 144, 111632. https://doi.org/10.1016/j.enpol.2020.111632.
- Steffen, B. (2020) 'Estimating the cost of capital for renewable energy projects', Energy Economics, 88, 104783. https://doi.org/10.1016/j.eneco.2020.104783.
- Zhang, D., Nazar, R. and Guo, M. (2023) 'Asymmetric green bonds-energy efficiency nexus in European Union countries: Evidence from econometric estimation', CLEAN – Soil, Air, Water, 51, 2200218. https://doi.org/10.1002/clen.202200218.
- Zhao, Q., Qin, C., Ding, L., Cheng, Y.-Y. and Vătavu, S. (2023) 'Can green bond improve the investment efficiency of renewable energy?', Energy Economics, 127, 107084. https://doi.org/10.1016/j.eneco.2023.107084.