Assessing Renewable Energy Project Efficiency through Green Sukuk: Evidence from Indonesia and Malaysia

Sri Ulfa [1], Tri Wahyuningsih [2], Rani Surya Resiana [3]

[1,2] *Economic and Business, Universitas Gadjah Mada,Yogyakarta, Indonesia*
[3] *Islamic Economy and Halal Industry, Economics and Business, Universitas Gadjah Mada, Yogyakarta, Indonesia*

Keywords
Green Sukuk,
Renewable Energy,
Islamic Finance,
Sukuk Structure,
OIC Sustainable Development

Abstract

Amidst global climate challenges, green sukuk has emerged as a shariah-compliant instrument to finance renewable energy projects, supporting the sustainable development goals (SDGs) in organisation of islamic cooperation (OIC) countries such as Indonesia and Malaysia. This study examines how green sukuk structures are associated with renewable energy project efficiency an aspect underexplored in existing literature, which has focused primarily on regulatory frameworks and market development rather than measurable project-level outcomes. To address this gap, the study integrates cost-effectiveness analysis (CEA) and data envelopment analysis (DEA) to evaluate four green sukuk-financed projects Indonesia's green sovereign sukuk 2018 and 2019, and Malaysia's tadau energy sukuk 2017 and quantum solar park sukuk 2018, drawing on official reports, prospectuses, and regulatory disclosures. Within the selected cases, the green sovereign sukuk 2018 (mudharabah; USD 50 million; state-driven) appeared associated with the highest relative efficiency (2.90 MW/USD million; 1,600 tons CO_2/year per USD million invested; DEA score 1.0000), while quantum solar park 2018 (ijarah; USD 247.50 million; private-sector) recorded the lowest (0.61 MW/USD million; 808.08 tons CO_2/year per USD million invested; DEA score 0.5051), associated with fragmentation across three dispersed sites. Tadau energy 2017 (mudharabah; DEA score 0.6310) and green sovereign sukuk 2019 (ijarah; DEA score 0.6250) achieved intermediate scores. Project scale, site consolidation, and governance arrangements appeared more consistently associated with relative efficiency than contract type alone. The study suggests that hybrid contracts combining ijarah and mudharabah elements, alongside harmonized regulatory frameworks, may optimize green sukuk efficiency, offering a replicable evaluation framework for OIC policymakers advancing sustainable financing aligned with environmental, social, and governance (ESG) principles and sustainable development goal (SDG) objectives.

Citation (APA)
Ulfa, S., Wahyuningsih, T., & Resiana, R. S. (2026). Assessing renewable energy project efficiency through green sukuk: Evidence from Indonesia and Malaysia. *Muslim Business and Economics Review, 5*(1) (176-215)

https://doi.org/10.56529/mber.v5i1.412

Submitted : 19 April 2025
Revised : 3 July 2025l
Accepted : 12 June 2026
Published - : 29 June 2026

Corresponding Author :
sriulfa@mail.ugm.ac.id

1. Introduction

The intensifying effects of climate change have heightened the need to accelerate the transition to renewable energy in order to reduce greenhouse-gas emissions and advance the sustainable development goals (SDGs), particularly SDG 7 on affordable and clean energy and SDG 13 on climate action (Ruan *et al*., 2024). Achieving this transition requires a substantial expansion of renewable-energy investment, particularly in developing economies. However, members of the organisation of islamic cooperation (OIC) commonly face limited access to capital, high investment risk, infrastructure constraints, and competing fiscal priorities, all of which restrict the scale and pace of renewable-energy deployment (Balakrishnan, 2025; Citalingam & Go, 2022; Donastorg *et al*., 2022). These challenges are pronounced in regions where infrastructure deficits and economic vulnerabilities exacerbate the funding gap, necessitating innovative financing mechanisms that align with both economic and environmental objectives.

Green sukuk has emerged as a shariah-compliant financing instrument that links Islamic finance principles with environmental sustainability objectives. By directing proceeds to eligible green assets and projects, green sukuk can support renewable-energy investment while complying with principles related to asset backing, the prohibition of riba, and the avoidance of excessive uncertainty (gharar) (Alam *et al*., 2023). The instrument therefore offers a potential bridge between ethical investment demand and the financing needs of low-carbon development, particularly in OIC countries where Islamic finance plays an important institutional role (Morea & Poggi, 2017; Raeni *et al*., 2022). Nevertheless, the growth of green sukuk issuance does not automatically demonstrate how efficiently funded projects translate financial resources into energy capacity and carbon-emission reductions. Assessing these project-level energy and environmental outputs therefore remains essential.

Indonesia and Malaysia provide a useful comparative setting for examining green sukuk in renewable-energy financing. Indonesia has developed a predominantly sovereign and state-coordinated model, in which green sukuk issuance is closely linked to national policy priorities and public-sector oversight. Malaysia, by contrast, has developed a more market-oriented model supported by its sustainable and responsible investment (SRI) Sukuk Framework, which enables greater participation by private issuers and project developers (Endri, Tahya Hania, *et al*., 2022; Rifansyah & Hakam, 2024). These institutional arrangements may be associated with different trade-offs involving project scale, governance, financing flexibility, risk allocation, and technological adaptation. They therefore provide a meaningful context for examining project-level efficiency rather than assuming that one national model is inherently superior to the other.

Although green sukuk has received increasing scholarly and policy attention, rigorous evaluations of project-level efficiency remain limited. Existing studies have largely examined regulatory frameworks, market development, shariah compliance, and investor demand, while relatively few have assessed whether green sukuk-financed projects deliver higher renewable-energy capacity or greater carbon-emission reductions relative to the funds allocated (Ali *et al*., 2024; Keshminder *et al*., 2022). In particular, limited evidence is available on indicators such as renewable-energy capacity per unit of investment and emission reduction per unit of investment. The relationship between sukuk structure, including contract type and financing mechanism, and project efficiency also remains insufficiently explored. These structural features should be interpreted as contextual factors that may be associated with project performance rather than as isolated causal determinants.

The study contributes to the literature on islamic finance and sustainable energy by moving the discussion beyond issuance volume, regulatory design, and market potential toward measurable project-level outcomes. Drawing on official prospectuses, regulatory reports, and project documentation, it offers a comparative assessment of how sukuk contract structures and financing mechanisms are associated with observed differences in governance arrangements, return predictability, and operational flexibility across selected projects. It also offers practical insights for regulators, sukuk issuers, and project developers seeking to improve the allocation of green financing resources. Rather than prescribing a single institutional model or deriving causal claims from a limited number of cases, the study highlights the importance of aligning sukuk structure, project scale, governance arrangements, and environmental performance indicators in the design of renewable-energy financing.

2. Literature Review

2.1. Green Sukuk as a Tool for Sustainable Financing

Green sukuk has emerged as a pivotal shariah-compliant financial instrument that integrates islamic finance principles with environmental sustainability to support renewable-energy initiatives. By adhering to the prohibitions on interest (riba), excessive uncertainty (gharar), and environmentally detrimental investments, green sukuk directs capital towards renewable-energy projects, such as solar photovoltaic and wind power facilities, thereby facilitating the transition to a low-carbon economy (Alnabulsi, 2024). Its alignment with ethical investment principles distinguishes it from conventional green bonds, particularly in Muslim-majority markets (Alnabulsi, 2024). Within the organisation of islamic cooperation (OIC) member states, green sukuk supports net-zero emissions targets and the sustainable development goals (SDGs), notably SDG 7 on affordable and clean energy and SDG 13 on climate action (Irfany *et al*., 2024). Global green sukuk issuances reached USD 10.5 billion in 2023, underscoring their potential to address the USD 3 trillion sustainable-financing gap (Pirgaip, 2024; Rose, 2025). However, inconsistent environmental, social, and governance (ESG) frameworks and greenwashing risks may undermine the credibility of green sukuk, highlighting the need for robust verification mechanisms, transparent reporting, and stronger investor confidence (Lokuwaduge & Silva, 2022; Sneideriene & Legenzova, 2025).

The green sukuk investment model allocates capital to shariah-compliant renewable-energy projects that use naturally regenerative resources, including solar, wind, hydropower, and biomass. As long-term and impact-oriented instruments, green sukuk may support the objectives of maqasid al-shariah, particularly environmental preservation (hifz al-bi'ah), while promoting inclusive development through improved access to clean energy in underserved regions (Rahim *et al*., 2024). These instruments typically employ contracts such as ijarah (asset leasing), mudharabah (profit-sharing), and wakalah (agency), thereby aligning expected returns with shariah principles and sustainable-finance objectives. Green sukuk may also facilitate blended finance by encouraging collaboration among public, private, and philanthropic stakeholders to mitigate investment risks in clean-energy projects, particularly in frontier markets (Moxey *et al*., 2021). By mobilizing ethical capital for renewable-energy investment, green sukuk may help reduce reliance on fossil fuels, mitigate climate-related financial risks, and support nationally determined contributions (NDCs) under the Paris Agreement.

The potential of green sukuk also extends to innovative technologies, including energy-storage systems and green hydrogen, which offer further opportunities for sustainable development (Criollo *et al*., 2024). However, scalability remains constrained by high capital intensity and limited technical capacity. Existing literature has predominantly focused on market development, regulatory frameworks, and shariah governance, while project-level evaluations of measurable environmental outcomes remain comparatively limited. Furthermore, the absence of standardized benchmarks, such as output-per-investment metrics, limits cross-jurisdictional comparison and policy harmonization. Longitudinal studies are therefore needed to assess the long-term effectiveness of green sukuk across the diverse economic and regulatory contexts of OIC member states and to strengthen their alignment with global climate-finance frameworks (Okpalajiaku & Harcourt, 2021; Wing & Zhong, 2015)

2.2. Comparative Approaches to Green Sukuk in Indonesia and Malaysia

Indonesia and Malaysia are among the leading green sukuk issuers in the organisation of islamic cooperation (OIC) and have adopted distinct approaches shaped by their regulatory and economic contexts. Indonesia's state-driven model developed through sovereign green sukuk issuance beginning in 2018 and is implemented through the green bond and green sukuk framework, which is closely aligned with national climate and development priorities (Putri *et al*., 2023). This framework may support policy coherence and public-sector oversight in the allocation of green financing. However, centralized governance may also constrain innovation and project flexibility because of bureaucratic procedures and institutional limitations (Keshminder *et al*., 2021; J. Zhang *et al*., 2024).

In contrast, Malaysia has developed a more market-oriented model, supported by the securities commission malaysia's sustainable and responsible investment (SRI) sukuk framework, introduced in 2014 and revised in 2021. The framework has encouraged private-sector participation and innovation in renewable-energy financing, as illustrated by green sukuk issuances for solar-energy projects, including the tadau energy sukuk in 2017 (Noordin & Haron, 2018; Zain, 2020). This approach may enhance market liquidity and provide greater flexibility for project developers. Nevertheless, ensuring consistent shariah compliance, environmental verification, and impact reporting across diverse issuers remains an important challenge (Ghardallou & Abaalkhail, 2024).

Malaysia's flexible and market-oriented model may therefore be more responsive to global financial and technological developments, whereas Indonesia's state-led model emphasizes alignment with national policy objectives and public-sector coordination. Existing comparative studies highlight Malaysia's potential liquidity advantage and Indonesia's policy coherence; however, project-level efficiency remains insufficiently explored (Camba *et al*., 2022; T. Rao & Mustapa, 2021). In particular, the literature provides limited evidence on whether the two institutional models produce different outcomes in terms of renewable-energy capacity or carbon-emission reduction relative to investment. Comparative analysis using standardized project-level indicators may therefore help inform green sukuk policy design in other OIC countries. Hybrid models that combine state oversight with private-sector innovation also merit further examination (Rusydiana & Rosadhillah, 2025).

2.3. Efficiency Measurement in Renewable Energy Financing

Efficiency measurement in renewable-energy financing is important for assessing whether investment generates meaningful economic and environmental outcomes, particularly in terms of energy capacity and carbon-emission reductions. Cost-effectiveness analysis (CEA) is commonly used to evaluate investment performance by comparing specified outputs with the financial resources allocated to a project. In renewable-energy financing, relevant indicators include renewable-energy capacity per USD million invested (MW per USD million) and annual carbon-emission reduction per USD million invested (annual tons of CO_2 avoided per USD million invested) (Niyazbekova *et al*., 2024; Norgren & Stankeviciene, 2024). These indicators provide a transparent basis for comparing the extent to which projects convert financial resources into measurable energy and environmental outputs. However, because CEA evaluates each outcome through a separate output-per-investment ratio, it does not provide a single relative-efficiency score when projects generate multiple outputs, such as renewable-energy capacity and carbon-emission reductions (Baal *et al*., 2018; Dar *et al*., 2021; Tan *et al*., 2013).

Data envelopment analysis (DEA) provides a complementary approach by measuring the relative efficiency of decision-making units across multiple inputs and outputs. DEA generates efficiency scores ranging from 0 to 1, where a score of 1.000 indicates that a project is positioned on the observed efficiency frontier, while scores below 1.000 indicate relative inefficiency compared with the best-performing projects in the sample (Ma *et al*., 2015; Rusydiana & Rosadhillah, 2025). Its application in solar projects demonstrates its usefulness for benchmarking project performance across different operational contexts (Tsolas, 2020; Villiers & Vermeulen, 2017). Nevertheless, DEA remains underutilized in research on green sukuk, particularly in assessing project-level efficiency across different scales, contractual structures, and risk profiles (Ari & Isik, 2022; Liu *et al*., 2023).

CEA and DEA therefore provide complementary perspectives for evaluating renewable-energy projects financed through green sukuk. CEA offers direct output-per-investment ratios, whereas DEA assesses relative performance across multiple dimensions. Future studies may extend this approach by combining DEA with complementary analytical methods to develop more nuanced efficiency assessments and improve resource-allocation decisions in islamic finance (Dellnitz *et al*., 2023; Rao *et al*., 2022). Developing hybrid efficiency models that are tailored to the institutional and contractual characteristics of islamic finance remains an important area for future research (Hassanpour, 2020).

2.4. The Role of Sukuk Structure in Project Efficiency

The structure of green sukuk may be associated with differences in fund allocation, risk sharing, governance arrangements, and project-management flexibility in renewable-energy financing. Ijarah, which is based on asset leasing, is generally associated with identifiable underlying assets and more predictable cash-flow arrangements. This structure may be suitable for large-scale projects that require clear contractual obligations, stable payment mechanisms, and strong institutional oversight, including state-coordinated renewable-energy projects in Indonesia (Endri, Hania, *et al*., 2022). Mudharabah, which is based on profit sharing, may provide greater flexibility for private-sector project managers and can support innovation in project implementation. However, it may also involve greater uncertainty in returns because outcomes depend on project performance and managerial capability (Nurzahira *et al*., 2019; Shahrul & Ishak, 2021). Wakalah, an agency-based structure, may offer an alternative arrangement by allowing an appointed agent to manage investment activities on behalf of investors while maintaining defined governance and monitoring arrangements (Fadhzana & Noor, 2024; Mahomed, 2024).

Nevertheless, the relationship between sukuk structure and project efficiency should be interpreted cautiously. Contract type is only one component of project design and may interact with issuer characteristics, project scale, technology, financing conditions, implementation capacity, and regulatory oversight. Therefore, an ijarah structure should not automatically be considered more efficient than a mudharabah structure, nor should a profit-sharing arrangement necessarily lead to greater innovation. Existing research has largely emphasized financial performance and contractual design, while giving less attention to how sukuk structures are associated with operational outcomes, such as renewable-energy capacity and carbon-emission reduction (Ahmad Tajjudin Rozman, 2022; Kumar, 2021; Luo & Chen, 2024). The present study therefore uses sukuk structure as an interpretive dimension for understanding observed differences in project efficiency, rather than treating it as a stand-alone causal determinant. Further research is needed to examine how contractual structures interact with institutional and project-specific conditions in shaping the effectiveness of green sukuk (Hassanpour, 2020).

2.5. Synthesis of Literature and Research Gap

Although Indonesia and Malaysia have developed distinct green sukuk frameworks, existing research has focused primarily on regulatory development, market expansion, shariah governance, and investor interest. Far less is known about how individual green sukuk-financed projects translate financial resources into measurable renewable-energy capacity and carbon-emission reductions. In particular, limited evidence is available on the relative efficiency of projects operating under different financing mechanisms and contractual structures.

This study addresses this gap through a comparative project-level assessment of selected green sukuk-financed renewable-energy projects in Indonesia and Malaysia. It combines cost-effectiveness analysis (CEA), using renewable-energy capacity and carbon-emission reduction per USD million invested, with data envelopment analysis (DEA) to assess relative technical efficiency across projects. The analysis further interprets observed efficiency profiles by considering sukuk structure, financing mechanism, and governance context. Given the limited number of cases, the study does not seek to establish causal effects; rather, it provides an exploratory comparison of how different project configurations are associated with observed energy and environmental outcomes.

3. Methodology

3.1. Research Design

This study adopts a comparative case study design using a mixed-methods approach to evaluate the efficiency of green sukuk in financing renewable energy projects in Indonesia and Malaysia. The study integrates qualitative institutional analysis with quantitative efficiency assessment to provide a comprehensive understanding of green sukuk performance (Ali *et al*., 2023; Endri, Tahya Hania, *et al*., 2022; Keshminder *et al*., 2022; Mohamed Yusoff *et al*., 2023). The research is conducted in three stages. First, a qualitative structural analysis is undertaken to identify differences in sukuk contract structures, financing mechanisms, governance arrangements, return predictability, and adaptability to technological innovation. Second, Cost-effectiveness analysis (CEA) is employed to evaluate the environmental outputs generated per unit of investment. Third, data envelopment analysis (DEA) is used to assess the relative technical efficiency of renewable energy projects financed through green sukuk. The integration of qualitative and quantitative findings allows the study to evaluate not only which projects are more efficient but also the institutional and structural factors that contribute to efficiency differences across projects and countries (Endri, Tahya Hania, *et al*., 2022; Ibrahim, 2015; Liu & Lai, 2021; Ulfah, Sukmana, Laila, *et al*., 2024).

3.2. Population and Sample

The study population encompasses all green sukuk issuances dedicated to renewable energy projects in Indonesia and Malaysia up to 2024. A purposive sampling strategy was employed to select four sukuk issuances based on the following criteria: (1) the availability of complete quantitative data on fund allocation (USD million), installed energy capacity (MW), and carbon emission reductions (tons of CO_2); (2) relevance to renewable energy projects, including solar photovoltaic power plants (PLTS) and (3) representation of structural diversity between state-driven and private-sector sukuk.

Based on these criteria, the selected sample consists of Indonesia's green sovereign sukuk 2018, which financed the 145 MW Cirata solar power plant green sovereign sukuk 2019, which supported various PLTS projects across Indonesia. Malaysia's tadau energy sukuk 2017, which financed a solar farm in Kudat, Sabah, and quantum solar park sukuk 2018, which financed solar park developments in Kedah, Melaka, and Terengganu.

The selected cases provide a focused exploratory comparison based on the availability of comparable project-level data. Given the limited number of decision-making units, the DEA results are interpreted as illustrative relative-efficiency benchmarks within the selected sample rather than as statistically generalizable estimates of green sukuk project efficiency (Li *et al*., 2011; Seiford, *et al*., 2011). Furthermore, the purposive sampling approach is consistent with focused comparative case study research, as it minimizes bias arising from incomplete data and facilitates a balanced comparison between sovereign and private-sector green sukuk. This sampling design also captures the distinctive characteristics of Islamic sustainable finance markets in Indonesia and Malaysia, thereby enhancing the analytical relevance of the cross-country comparison.

3.3. Data Collection

Data were sourced from secondary documents to ensure validity and reliability. For Indonesian sukuk, data on the green sovereign sukuk 2018 and 2019 were obtained from official ministry of finance reports, supplemented by project reports from the financial services authority (OJK) and the ministry of energy and mineral resources (ESDM), while data on the tadau energy sukuk 2017 and quantum solar park sukuk 2018 were retrieved from official reports by bursa Malaysia and the securities commission Malaysia, including publicly available sukuk prospectuses and post-issuance impact reports. IRENA technical reports were consulted to cross-validate project-level energy capacity and carbon emission reduction figures used in the analysis. A systematic document analysis approach was employed to extract qualitative data, comprising contract types, financing mechanisms, and governance arrangements, and quantitative data, comprising fund allocation in USD million, installed energy capacity in megawatts, and carbon emission reductions in tons of CO_2, with data triangulation conducted by cross-verifying official reports against independent sources, including IRENA technical reports and peer-reviewed journals, and primary official documents retained as reference values where discrepancies arose (Bowen, 2009). Quantitative data were compiled in spreadsheets and processed using RStudio (version 4.3), with CEA ratios calculated directly from project-level data and DEA implemented using the benchmarking and DEA packages under an input-oriented constant returns to scale (CRS) model, specifying total investment as the input and energy capacity and carbon emission reduction as outputs, consistent with the policy objective of minimizing financial inputs for a given level of renewable energy and environmental outcomes.

3.4. Operational Definition of Variables

To assess the efficiency and effectiveness of financing renewable energy projects through green sukuk, this study employs a set of input, output, and qualitative variables, operationally defined based on authoritative data sources and relevant literature (Cooper, Li, *et al*., 2011; Cooper, Seiford, *et al*., 2011). These variables encompass total investment as the input and energy capacity and emission reduction as outputs within the data envelopment analysis (DEA) framework (Cooper, Li, *et al*., 2011; Feng *et al*., 2015; Wang *et al*., 2019), and efficiency ratios in the cost-effectiveness analysis (CEA) approach. Additionally, qualitative variables such as contract type, issuing country, and sukuk issuer status are incorporated to provide institutional and structural context to the analysis. Each variable is formulated to ensure measurement clarity, alignment with analytical objectives, and the validity of the data source.

Table 1. Operational Definition of Variables for DEA and CEA Analysis

No	Variable	Type	Operational Definition	Unit	Data Source
1	Total Investment	Input (DEA)	Total funds allocated to the green sukuk project during the issuance period	Million USD	Ministry of Finance RI; Bursa Malaysia; Securities Commission Malaysia.
2	Energy Capacity	Output (DEA & CEA)	Total installed renewable energy generation capacity at project commissioning	Megawatt (MW)	Ministry of Energy RI; Bursa Malaysia.
3	Emission Reduction	Output (DEA & CEA)	Total CO_2 emissions avoided annually from installed renewable energy capacity	Ton CO_2/year	Ministry of Energy RI; Bursa Malaysia.
4	MW per Million USD	Ratio (CEA)	Installed energy capacity generated per unit of total green sukuk investment	MW/Million USD	Calculated from official project data.
5	Annual CO_2 Avoided per USD Million Invested	Ratio (CEA)	Annual CO_2 emissions avoided per unit of total green sukuk investment	tCO_2/year per USD million invested	Calculated from official project data.
6	Contract Type	Qualitative	Shariah contract type governing the sukuk structure: ijarah (asset leasing) or mudharabah (profit-sharing)	Ijarah / Mudharabah	Official sukuk prospectuses; OJK & SC Malaysia documents; Sukmana & Ibrahim (2021).
7	Country	Qualitative	Country of the sukuk issuer, distinguishing Indonesia's state-driven model from Malaysia's market-oriented model	Indonesia / Malaysia	Official issuer reports (Ministry of Finance RI; Bursa Malaysia; SC Malaysia).
8	Issuer Type	Qualitative	Institutional status of the sukuk issuer: sovereign government or private-sector project developer	1 = Government, 0 = Private	Official issuer profiles (Ministry of Finance RI; Bursa Malaysia).

3.5. Qualitative Approach

The first dimension examines the type of shariah contract, comparing the effectiveness of ijarah (asset leasing) and mudharabah (profit-sharing) contracts. Ijarah contracts, as implemented in Indonesia's green sovereign sukuk of 2018 and 2019, tend to ensure stable cash flows and legal certainty, making them well-suited to large-scale, state-managed projects with centralized governance structures. Conversely, mudharabah contracts, as seen in Malaysia's tadau energy project, foster technological innovation and operational flexibility but entail higher managerial risks due to reliance on profit-sharing schemes and private-sector management (Ghaemi Asl *et al*., 2023; Gundogdu, 2019; Harahap *et al*., 2023; Ulfah, Sukmana, Laila, *et al*., 2024).

The second dimension focuses on financing mechanisms, comparing state-managed projects with those managed privately. government-facilitated projects, such as indonesia's green sovereign sukuk, are expected to benefit from robust regulatory frameworks, stable fiscal access, and the capacity to develop large-scale infrastructure. In contrast, privately managed projects such as Malaysia's quantum solar park sukuk 2018, which employs an ijarah structure without state backing, may face challenges related to fragmented project locations and technical coordination that affect technical efficiency and operational costs (Basri *et al*., 2015; Keshminder *et al*., 2022; Liu & Lai, 2021; Mohamed Yusoff *et al*., 2023). The third dimension examines non-technical project characteristics, namely: (1) governance arrangements, (2) return predictability, and (3) adaptability to market and technological conditions. These dimensions are interpreted qualitatively through documentary evidence from sukuk prospectuses, regulatory reports, and project disclosures. Rather than being operationalized as numerical scores, these dimensions serve to contextualize the cross-project differences observed in cost-effectiveness and relative DEA efficiency.

The analytical approach is developed through an integrative conceptual framework that interlinks contractual structures, financing actors, and technical and institutional efficiency dimensions. Rather than mapping causal relationships, the analysis focuses on examining associations between contract types (ijarah vs mudharabah), issuer status (state vs private), and efficiency outcomes measured through DEA and CEA models, consistent with the exploratory and comparative nature of this study. A comparative narrative analysis is conducted for the two primary countries in this study, Indonesia and Malaysia (Ali *et al*., 2023; Basri *et al*., 2015; Endri, Tahya Hania, *et al*., 2022; Keshminder *et al*., 2022; Liu & Lai, 2021; Mohamed Yusoff *et al*., 2023). Indonesia demonstrates strong institutional support from the financial services authority (OJK) and the ministry of finance, with a focus on large-scale solar (PLTS) projects. Malaysia, by contrast, has developed a more mature and dynamic Islamic finance ecosystem, supporting private-sector innovation through flexible sukuk structures.

This qualitative analysis seeks to interpret the underlying factors associated with the observed efficiency profiles of green sukuk-financed renewable energy projects, extending beyond the quantitative assessment of efficiency scores. By incorporating contractual arrangements and institutional characteristics into the analytical framework, the study provides a more comprehensive understanding of green sukuk performance across different project contexts. The findings offer insights not only for Indonesia and Malaysia but also for other OIC member countries, including Saudi Arabia and the United Arab Emirates, by providing a reference framework for designing context-sensitive and financially sustainable green sukuk policies aligned with broader sustainability objectives and the sustainable development goals (SDGs).

3.5.1. Quantitative Approach: Cost-Effectiveness Analysis (CEA)

To evaluate the economic efficiency of renewable energy projects financed through green sukuk, this study employs cost-effectiveness analysis (CEA) as a primary quantitative approach (Bojke *et al*., 2017; Higgins & Harris, 2012; X. Zhang *et al*., 2024). CEA is particularly suitable for assessing the effectiveness of financial resources in generating measurable sustainability outcomes, as it directly relates investment costs to project outputs. In the context of green sukuk financing, this approach enables the evaluation of how efficiently invested capital translates into renewable energy capacity expansion and carbon emission reductions, both of which are critical indicators of energy transition and climate change mitigation efforts (Ali *et al*., 2023; Karim, 2023; F. H. Liu & Lai, 2021; Ulfah, Sukmana, Laila, *et al*., 2024). Accordingly, efficiency is conceptualized not merely as cost minimization but as the ability to maximize environmental and energy-related benefits from a given level of financial investment.

The primary objective of CEA in this study is to assess the cost-effectiveness of renewable energy projects funded through green sukuk by measuring the volume of outputs generated per unit of investment (Ibrahim, 2015; F. H. Liu & Lai, 2021; Ulfah, Sukmana, Laila, *et al*., 2024). This evaluation is conducted by comparing total investment against two key output metrics: (1) renewable energy capacity generated, measured in megawatts per million USD (MW/USD million), and (2) annual carbon emissions avoided, measured in tons of CO_2 per year per USD million invested (tCO_2/year per USD million invested). A higher ratio indicates greater cost-effectiveness, reflecting more energy capacity or emission reduction achieved per unit of financial input. The analysis is performed at the project level, with each green sukuk treated as an independent observational unit. This approach enables a systematic comparison of the most cost-effective projects in terms of sustainable development outcomes

CEA for Renewable Energy Capacity:

$$\mathrm{CEA}_{\mathrm{Energy}} = \frac{\text{Renewable Energy Capacity (MW))}}{\text{Total Green Sukuk Investment (USD million)}}$$

Unit: MW per USD million

CEA for Annual CO_2 Emission Reduction

$$\mathrm{CEA}_{\mathrm{Energy}} = \frac{\text{Renewable Energy Capacity (MW))}}{\text{Total Green Sukuk Investment (USD million)}}$$

Unit: Tons of CO_2/year per USD million invested

The analysis was conducted using a descriptive quantitative approach, employing RStudio for computation and visualization. Results were presented through bar charts to illustrate cost-effectiveness comparisons across projects, enabling identification of efficiency patterns based on project scale, contractual structure, and issuer type.

3.5.2. Quantitative Approach: Data Envelopment Analysis (DEA)

This study employs data envelopment analysis (DEA) as a quantitative approach to evaluate the relative technical efficiency of renewable energy projects financed through green sukuk. DEA was selected for its ability to assess efficiency across multiple inputs and outputs without requiring prior assumptions about the functional form of the production relationship, making it well-suited to the evaluation of public-sector and energy projects that involve complex combinations of financial and environmental variables (Cooper, Li, *et al*., 2011; Cooper, Seiford, *et al*., 2011).

The unit of analysis in DEA is the decision-making unit (DMU), defined in this study as individual green sukuk-financed renewable energy projects. Four DMUs are analyzed: (1) Green Sovereign Sukuk 2018 (Cirata Solar Plant, Indonesia), (2) green sovereign sukuk 2019 (PLTS, Indonesia), (3) tadau energy sukuk 2017 (Solar Farm, Malaysia), and (4) quantum solar park sukuk 2018 (Solar Park, Malaysia). Although DEA conventionally benefits from larger samples, its application to a small but well-defined set of DMUs is appropriate when reliable and comparable data are available for all units and the analytical objective is cross-project benchmarking rather than statistical inference.

The input and output variables are selected based on their relevance to the financial and environmental performance of renewable energy projects. Total investment (USD million) is specified as the single input variable, representing the financial resources mobilized through each sukuk issuance. The output variables consist of installed renewable energy capacity (MW) and carbon emission reductions (tons of CO_2), capturing the energy and environmental outcomes generated per unit of investment. This input-output specification is consistent with the policy objective of minimizing financial inputs for a given level of renewable energy and environmental outcomes, and aligns with established approaches in the DEA-based energy efficiency literature.

The model adopts an input-oriented constant returns to scale (CRS) framework, as introduced by Charnes *et al*. (1978). The input-oriented approach reflects the practical objective of minimizing investment expenditure while maintaining a given level of renewable energy and environmental outputs, consistent with the resource allocation priorities of green sukuk issuers and policymakers. The CRS assumption is adopted because the projects in this study operate under comparable financing conditions and policy objectives, and because CRS provides an overall technical efficiency score that is appropriate for cross-project comparison without additional assumptions about scale behavior. Each DMU is assigned an efficiency score ranging from 0 to 1, where a score of 1.0000 indicates that the project lies on the observed efficiency frontier, while scores below 1.0000 indicate relative inefficiency compared with the best-performing projects in the sample. The DEA analysis was implemented in RStudio using the Benchmarking and DEA packages.

4. Results and Discussion

4.1. Structure and Efficiency of Green Sukuk: A Comparative Analysis of Indonesia and Malaysia

This study examines the shariah-compliant financial structure and efficiency of green sukuk as a financing instrument for renewable energy projects in Indonesia and Malaysia, two leading members of the OIC. Using a descriptive-comparative approach, the study analyzes green sukuk contract types (ijarah vs mudharabah) and financing mechanisms (state-driven, private-sector) in project management and the energy sector across three efficiency dimensions, governance, predictability of returns, and adaptability to technological innovation. Data were sourced from official prospectuses, annual reports, and market disclosures by Indonesia's financial services authority (OJK) and bursa malaysia, supplemented by regulatory guidelines and industry reports to ensure a complete dataset beyond historical records. The analysis elucidates how shariah-compliant structures influence the efficiency of renewable energy financing and offers insights for scaling green sukuk in global Islamic markets.

Table 2. Structural Characteristics of Green Sukuk

Sukuk	Contract	Mechanism	Manager	Sector
Green Sovereign Sukuk 2018 (Cirata)	*Ijarah*	State-driven	Ministry of Finance	PLTS (145 MW)
Green Sovereign Sukuk 2019 (PLTS)	*Ijarah*	State-driven	Ministry of Finance	PLTS
Tadau Energy Sukuk 2017	Mudharabah	Private-sector	Tadau Energy Sdn. Bhd.	Solar Farm (50 MW)
Quantum Solar Park Sukuk 2018	***Mudharabah***	Private-sector	Quantum Solar Park Sdn. Bhd.	Solar Park (150 MW)

Note: The table is compiled based on official prospectuses and reports from OJK and Bursa Malaysia.

The results reveal distinct structural and efficiency profiles for green sukuk in Indonesia and Malaysia. In Indonesia, the green sovereign sukuk issuances of 2018 and 2019 use an ijarah structure and are managed through a state-driven financing mechanism. This asset-backed arrangement is associated with relatively clear contractual obligations, centralized oversight, and more predictable cash-flow arrangements (Keshminder *et al*., 2021). The involvement of the ministry of finance and regulatory oversight by the financial services Authority may provide a governance context that supports accountability and investor confidence. However, the centralized and large-scale nature of these projects may also limit flexibility in responding to changing technological conditions, such as the adoption of new storage technologies or project-level design adjustments (Thomas *et al*., 2020).

In Malaysia, Tadau Energy Sukuk 2017 uses a mudharabah structure and is managed by a private-sector project developer. Its profit-sharing arrangement may provide greater managerial flexibility and facilitate the adoption of project-specific technological approaches. However, this structure may also involve greater uncertainty in return realization because project performance is closely linked to managerial capability and operating conditions. Quantum Solar Park Sukuk 2018, which uses an mudharabah structure, combines private-sector management with more predictable asset-linked cash-flow characteristics (Shahrul & Ishak, 2021). Nevertheless, its multi-site project configuration may create additional coordination and logistical challenges (Nguyen *et al*., 2023). These qualitative observations are used to interpret the observed CEA and DEA results and should not be interpreted as causal evidence that one contract type is inherently superior to another (Ali & Mawali, 2023).

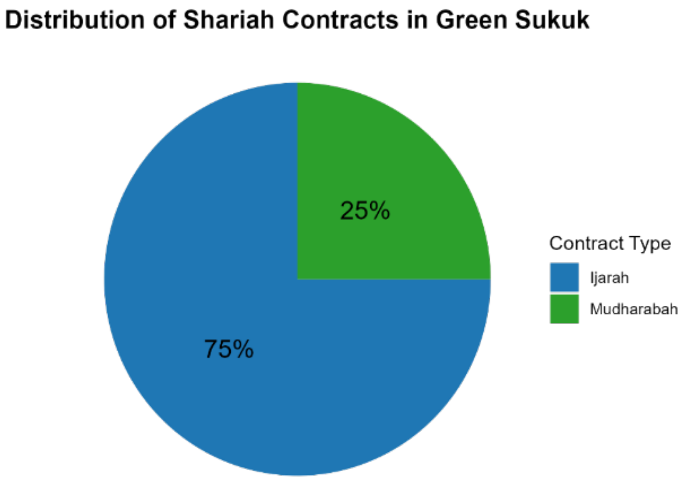

Figure 1. Distribution of Shariah Contracts

A pie chart illustrates that ijarah dominates (75%; Green sovereign sukuk 2018, 2019, Quantum solar) over mudharabah (25%; Tadau Energy) in OIC green sukuk markets. This preference for ijarah reflects its alignment with risk-averse investors and OJK's regulatory stability (Utami, 2025). Mudharabah's smaller share highlights its niche role in innovation-driven markets, such as Malaysia (Shahrul *et al.*, 2025).

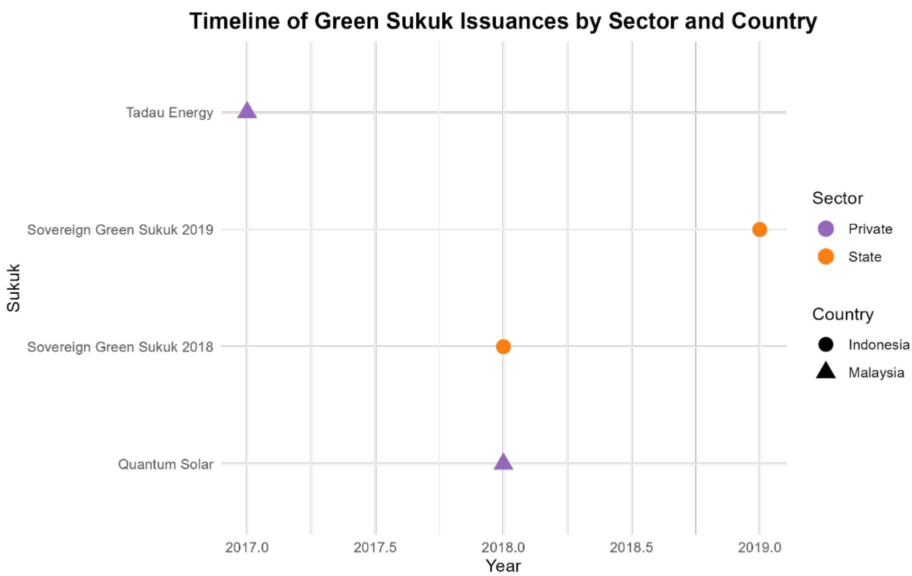

Figure 2. Sukuk Issuance Timeline

A timeline (2017–2019) underscores Indonesia's fiscal commitment through green sovereign sukuk (2018, 2019) and Malaysia's private-sector innovation via tadau energy (2017) and Quantum solar (2018) positioning both nations as pioneers in green sukuk within the OIC (Liu & Lai, 2021).

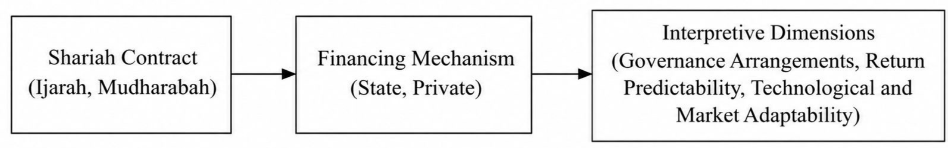

Figure 3. Conceptual Framework

The conceptual framework situates sukuk contract structures and financing mechanisms within three interpretive dimensions, governance arrangements, return predictability, and adaptability to technological and market conditions. These dimensions are employed to provide an institutional and contextual interpretation of cross-project variation in cost-effectiveness and relative technical efficiency. Accordingly, the framework does not specify causal relationships, nor does it operationalize these dimensions as numerically scored measures. Within the selected cases, the findings suggest that sukuk structural characteristics were associated with distinct patterns of governance, return predictability, and adaptability, though no causal claims can be drawn from this exploratory comparison. Indonesia's state-driven ijarah sukuk appeared to be linked to stronger governance arrangements and more predictable return profiles, making it appear suitable for large-scale projects such as the 145 MW Cirata PLTS. The asset-backed ijarah structure appeared consistent with OJK's regulatory focus on stability, which may have supported investor confidence through transparent compliance mechanisms (Ulfah *et al*., 2024). However, within the selected cases, this structural characteristic also appeared to be associated with constrained responsiveness to emerging technological advancements, such as next-generation solar panels or battery storage, which are considered essential for enhancing renewable energy efficiency (Khalili *et al*., 2025). This observation appears consistent with broader patterns noted in the Islamic finance literature, where state-backed instruments have been associated with an emphasis on risk mitigation rather than innovation (Alsaghir, 2023).

In contrast, Malaysia’s mudharabah based tadau energy sukuk prioritizes adaptability, enabling private managers to adopt cutting-edge solar technologies. This flexibility is facilitated by BNM’s market-oriented regulations, which encourage innovation but introduce volatility in returns, necessitating enhanced risk management frameworks (Nawal Kasim & Salman, 2014). The quantum solar park sukuk, using ijarah, strikes a balance by ensuring stable cash flows while operating within Malaysia's flexible regulatory environment. However, its private-sector nature limits its ability to drive technological breakthroughs relative to mudharabah based structures (Rozman & Azmi, 2022).

The comparative analysis reveals a trade-off between stability and innovation, shaped by regulatory contexts and project objectives. Indonesia's ijarah model may be well-suited for risk-averse investors and large-scale public projects, and appeared aligned with national energy transition goals (Rozman & Azmi, 2022). Malaysia's mudharabah model suits private issuers seeking technological leadership, though it requires strong governance to maintain investor trust (Shahrul & Ishak, 2021). These findings extend beyond historical data, incorporating regulatory insights and market trends to project the potential of green sukuk in OIC markets, such as Saudi Arabia and the UAE. For instance, Indonesia's ijarah model may offer lessons for other OIC countries seeking to develop large-scale, state-coordinated green sukuk (Endri, Hania, *et al*., 2022). Malaysia's mudharabah approach may offer insights for other OIC countries seeking to develop market-oriented, private-sector-driven green sukuk frameworks.

To optimize efficiency, future studies may examine whether hybrid sukuk structures, such as musharakah-murabahah arrangements, can combine elements of return predictability with greater operational flexibility in renewable-energy financing (Kuanova, 2025). Such arrangements may offer a useful direction for addressing potential adaptability constraints in state-coordinated projects and governance challenges in private-sector initiatives. Future research may develop and validate a transparent qualitative assessment framework for governance arrangements, return predictability, and technological adaptability using explicit indicators, documentary evidence, and a broader set of green sukuk projects (Keshminder *et al*., 2021).

4.2. Efficiency Analysis of Renewable Energy Projects Financed by Green Sukuk Using Cost-Effectiveness Analysis (CEA)

This study employs cost effectiveness analysis (CEA) to evaluate the economic efficiency of four green sukuk issuances financing renewable energy projects in Indonesia and Malaysia, two pioneering countries in sustainable shariah-compliant financing within the OIC. The analysis measures energy capacity ratios (MW per USD million) and carbon emission reductions (ton CO_2/year per USD million invested) to compare cost-effectiveness across the sukuk (S. Li *et al*., 2024; X. Zhang *et al*., 2024), utilizing data from official reports by the Ministry of Finance of the Republic of Indonesia, Bursa Malaysia, and sukuk prospectuses. This study enriches the literature on Islamic finance by providing empirical evidence of the role of green sukuk in supporting energy transitions in alignment with environmental, social, and governance (ESG) criteria and the sustainable development goals (SDGs) (Ahmed *et al*., 2019; X. Zhang *et al*., 2024).

Table 3 illustrates the comparative cost-effectiveness of selected green sukuk-financed energy projects, evaluated using two key metrics, energy capacity delivered (MW) per USD million and annual CO_2 emissions avoided per USD million invested (Li *et al*., 2024; Zhang *et al*., 2024). Among the projects analyzed, the 2018 green sovereign sukuk for the Cirata solar photovoltaic (PLTS) plant in West Java, Indonesia, appeared to be associated with the highest cost-effectiveness within the selected cases, yielding 2.90 MW and offsetting 1,600 tons of CO_2/year per USD million invested invested. In contrast, the 2019 green sovereign sukuk financing solar PV (PLTS) projects exhibited the lowest energy efficiency at 0.67 MW/USD million, despite achieving a substantial emissions reduction of 1,000 tCO_2/year per USD million invested. Meanwhile, Malaysia-based solar projects tadau energy (2017) and quantum solar (2018) displayed moderate performance, with energy efficiencies of 0.84 and 0.61 MW/USD million and emissions reductions of 1,009.59 and 808.08 tCO_2/year per USD million invested, respectively. These findings highlight the heterogeneous nature of project-level cost-effectiveness in the green finance domain, suggesting that project type (Vyas & Jha, 2017), technological maturity, and implementation context appeared to be associated with differences in both environmental and economic outcomes across the selected cases. This comparative analysis offers exploratory insights for policymakers and investors seeking to better understand the allocation of green capital towards projects with higher sustainability returns (Azhgaliyeva *et al*., 2020; Zhu *et al*., 2024).

Table 3. Cost-Effectiveness of Selected Green Sukuk-Financed Projects

Sukuk	Investment (USD Million)	MW per USD Million	Tons of CO_2/year per USD million invested
Green Sovereign Sukuk 2018 (Cirata PLTS, Indonesia)	50.00	2.90	1,600.00
Green Sovereign Sukuk 2019 (PLTS, Indonesia)	30.00	0.67	1,000.00
Tadau Energy Sukuk 2017 (Solar Farm, Malaysia)	59.43	0.84	1,009.59
Quantum Solar Park Sukuk 2018 (Solar Park, Malaysia)	247.50	0.61	808.08

Note: Investment, installed capacity, and annual CO_2 avoidance data are compiled from official green sukuk reports, project disclosures, and sukuk prospectuses.

The data evaluation reveals thats the green sukuk 2018, which financed the 145

MW Cirata PLTS in Indonesia, is the most efficient green sukuk, achieving a ratio of 2.90 MW per USD million and a carbon emission reduction of 1,600 tons CO_2/year per USD million invested. This efficiency is driven by the project's large scale, centralized management by the ministry of finance and the ministry of energy and mineral resources (ESDM), and the use of optimal solar technology (Ali *et al*., 2023; Endri, Tahya Hania, *et al*., 2022; Li *et al*., 2022; Wang *et al*., 2022). The stringent regulations of Indonesia's financial services authority (OJK) also supported effective fund allocation. Tadau Energy 2017, a private-sector initiative in Malaysia (Keshminder *et al*., 2022), recorded a ratio of 0.84 MW per USD million and a carbon emission reduction of 1,009.59 tons CO_2/year per USD million invested, demonstrating competitive efficiency, particularly in environmental impact, due to advanced photovoltaic technology and the flexible regulatory framework of bank negara malaysia (BNM), despite the mudharabah contract limiting project scale. Conversely, green sukuk 2019 (PLTS) in Indonesia) and quantum solar 2018 (Malaysia) exhibited lower efficiency, with 0.67 MW and 1,000 ton CO2 per USD million, and 0.61 MW and 808.08 tons CO2 per USD million, respectively, due to project fragmentation that increased logistical costs and reduced impact.

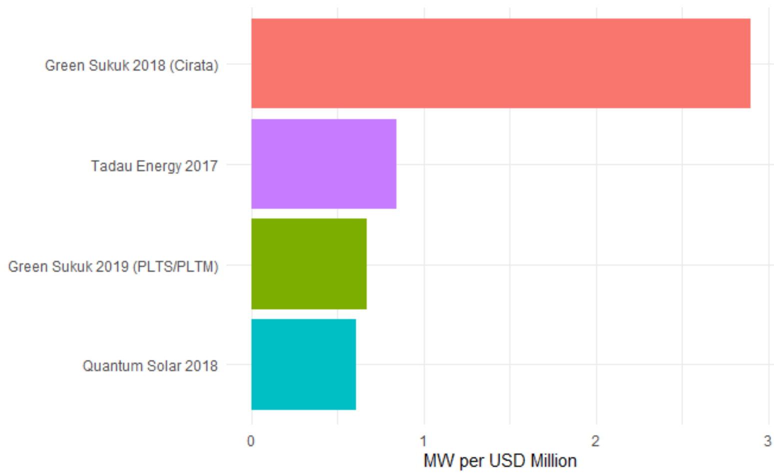

Figure 4. Cost-Effectiveness: Energy Capacity Comparison

This horizontal bar chart compares energy capacity across sukuk. The green sukuk 2018, represented by the longest red bar at 2.90 MW per USD million, demonstrates the highest efficiency, reflecting the advantage of large-scale projects and centralized governance in optimizing investment. Tadau energy 2017, with a purple bar at 0.84 MW per USD million, ranks second, indicating that private-sector projects with advanced technology can remain competitive despite being on a smaller scale (Ari & Koc, 2021; Sajjad *et al*., 2024; Warren, 2019; Zhang *et al*., 2024). Green sukuk 2019, with a green bar at 0.67 MW per USD million, places third, highlighting efficiency constraints due to projects being dispersed across multiple locations. Quantum solar 2018, with the shortest blue bar at 0.61 MW per USD million, exhibits the lowest efficiency, underscoring the negative impact of project fragmentation and small scale on energy capacity.

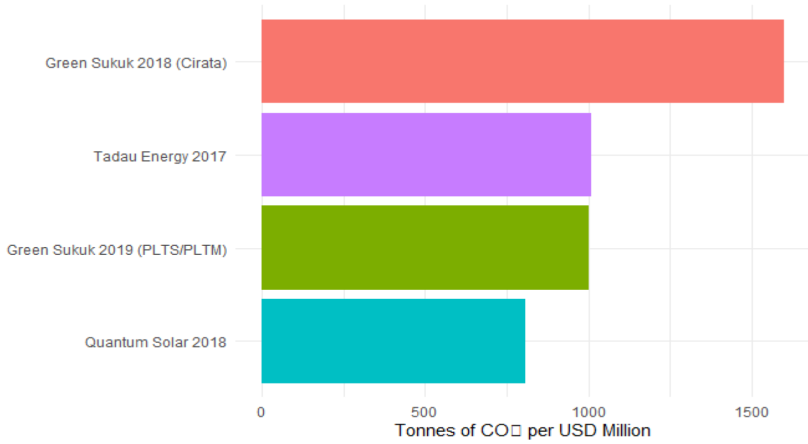

Figure 5. Cost-Effectiveness: Annual CO_2 Avoidance per USD Million Invested

This diagram illustrates the carbon emission reductions across the sukuk. The green sukuk 2018 again leads with the longest red bar at 1,600 tons CO_2/year per USD million invested, affirming its environmental contribution due to the project's scale and efficient technology. Tadau energy 2017, with a purple bar at 1,009.59 tons of CO_2/year per USD million invested, demonstrates competitive performance, highlighting the potential of private-sector initiatives in environmental sustainability through advanced photovoltaic technology. Green sukuk 2019, with a green bar at 1,000 tons of CO_2/year per USD million invested, is slightly below tadau energy, indicating that despite fragmentation, the project still delivers a relevant environmental impact. Quantum solar 2018, with the shortest blue bar at 808.08 tons of CO_2/year per USD million invested, demonstrates the lowest environmental contribution, consistent with its limitations in scale and project fragmentation.

The data evaluation and visual representations indicate that the cost-effectiveness of green sukuk depends on project scale, technology, and governance (Li *et al*., 2024; Zhang *et al*., 2024; Zhu *et al*., 2024). The green sukuk 2018 excels due to economies of scale and institutional support, tadau energy stands out in environmental sustainability, while green sukuk 2019 and quantum solar are hindered by fragmentation (Abdullah & Keshminder, 2022; Endri, Tahya Hania, *et* *al*., 2022; Noordin *et al*., 2018).

4.3. Effectiveness Assessment of Renewable Energy Projects Financed by Green Sukuk Using Data Envelopment Analysis (DEA)

This study employs data envelopment analysis (DEA), a non-parametric frontier methodology, to evaluate the technical efficiency of four green sukuk issuances financing renewable energy projects in Indonesia and Malaysia, leading nations in shariah-compliant sustainable financing within the OIC. The DEA model, configured with a constant returns to scale (CRS) input-oriented framework, assesses efficiency by comparing a single input investment (in USD million) against two outputs: energy capacity (in megawatts, MW) and carbon dioxide (CO_2) emission reductions (in tons per year). Data were sourced from authoritative, publicly available reports, including those from the ministry of finance of the republic of Indonesia, Bursa Malaysia, Bank Negara Malaysia, and sukuk prospectuses, ensuring robustness. This approach facilitates the systematic benchmarking of green sukuk projects, identifying optimal input-output configurations by leveraging verified, high-quality sources.

Table 4: Input, Output, and Efficiency Scores of Green Sukuk Projects

Green Sukuk	Investment (USD Million)	Capacity (MW)	Annual CO_2 Reduction (tCO_2/year)	Efficiency Score
Green Sovereign Sukuk 2018 (Cirata)	50.00	145	80,000	1.0000
Green Sovereign Sukuk 2019 (PLTS)	30.00	20	30,000	0.6250
Tadau Energy 2017	59.43	50	60,000	0.6310
Quantum Solar 2018	247.50	150	200,000	0.5051

Note: Note: Investment, installed capacity, and annual CO_2 avoidance data are compiled from official green sukuk reports, project disclosures, and sukuk prospectuses. Efficiency scores are relative to the four selected DMUs.

The DEA results reveal meaningful variation in relative technical efficiency across the four green sukuk projects. The analysis was implemented in RStudio (version 4.3) using the benchmarking and DEA packages, configured under an input-oriented constant returns to scale (CRS) model, with total investment (USD million) as the single input and installed energy capacity (MW) and annual CO_2 emission reduction (tons/year) as the two outputs efficiency scores range from 0 to 1 and reflect relative efficiency among the four DMUs only, not against an external benchmark. Within the four selected decision-making units, Green Sovereign Sukuk 2018, which financed the Cirata solar photovoltaic project in Indonesia, achieved the highest relative efficiency score of 1.0000. This result places the project on the observed efficiency frontier of the present sample, against which the remaining three projects are benchmarked. The score should therefore be interpreted as a relative comparison within the selected cases rather than as evidence of absolute efficiency or superior performance across the broader green sukuk market. Within the selected cases, this performance appeared to be associated with the project's large-scale design, centralized governance under the Indonesian government, and the adoption of advanced solar technology, which minimizes per-unit costs and maximizes environmental impact (Amiruddin *et al*., 2024; Maulidia *et al*., 2019). Stringent regulatory oversight by Indonesia's financial services authority (OJK) also appeared to support efficient resource allocation, aligning with governance frameworks that enhance sustainable finance outcomes (Ardiana *et al*., 2025; Kusnawirawan *et al*., 2025; Setyowati, 2023; Suaidi, 2025). These observations are consistent with evidence that large-scale, government-backed projects tend to achieve more favorable input-output ratios than smaller or geographically fragmented initiatives, though no causal inference is drawn from this limited four-DMU sample.

In contrast, quantum solar 2018 recorded the lowest relative efficiency score of 0.5051, despite its substantially larger investment of USD 247.50 million and significant absolute outputs of 150 MW and 200,000 tons of CO_2 reduction annually. Within the selected cases, this outcome appeared to be associated with the project's fragmentation across three geographically dispersed sites (Kedah, Melaka, and Terengganu), which increases logistical and coordination costs a challenge consistently noted in multi-site project management contexts (Hilali *et al*., 2023; Torabi & Hassini, 2009). The comparatively lower relative efficiency score of the multi-site project suggests that site configuration may warrant further consideration in future project planning. However, this observation should not be interpreted as conclusive evidence that centralized or single-site development will necessarily produce superior efficiency in other green sukuk contexts.

Tadau Energy 2017 (USD 59.43 million; 50 MW; 60,000 tons CO_2 reduction per year; DEA score 0.6310) and green sovereign sukuk 2019 (USD 30.00 million; 20 MW; 30,000 tons CO_2 reduction per year; DEA score 0.6250) achieved intermediate efficiency scores, placing them between the frontier project and the least efficient unit. Within the selected cases, tadau energy appeared to benefit from Malaysia's flexible regulatory framework under bank negara malaysia (BNM) and advanced photovoltaic technology, but was constrained by its smaller scale and complexities associated with the mudharabah contract, which introduced risk-sharing challenges (Abd Aziz *et al*., 2024). Similarly, the green sovereign sukuk 2019 appeared to face inefficiencies associated with the fragmentation of its solar (PLTS) projects across multiple sites, elevating operational costs relative to the more consolidated Cirata project.

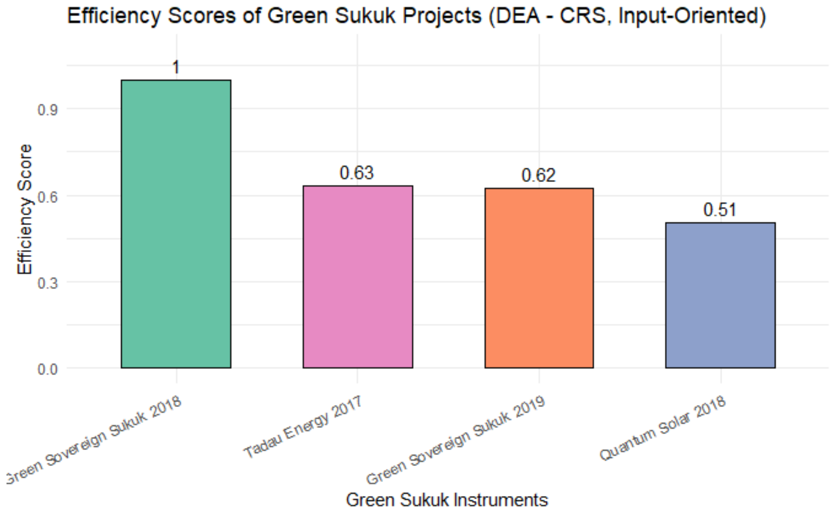

Figure 6. Efficiency Scores of Green Sukuk Projects (DEA – CRS, Input-Oriented)

Figure 6 illustrates the relative DEA efficiency scores of the four selected projects under the input-oriented CRS model. Among the four projects, Green Sovereign Sukuk 2018 recorded the highest relative efficiency score and formed the observed efficiency frontier, whereas Tadau energy 2017 and green sovereign sukuk 2019 recorded intermediate scores and quantum solar 2018 recorded the lowest score. The observed variation is consistent with differences in project scale, site configuration, governance arrangements, and implementation context. However, the four-DMU sample does not permit causal inference regarding the independent effect of any single factor. The findings should therefore be interpreted as exploratory evidence of relative efficiency differences among the selected projects rather than as general evidence that a particular contract type, financing mechanism, or project configuration necessarily produces superior efficiency (Firoozi *et al*., 2024; Hassan *et al*., 2024; Malek *et al*., 2024; Voudouris *et al*., 2012).

The analysis leverages historical data from authoritative sources, ensuring the reliability and validity of the data envelopment analysis (DEA) results and providing a robust foundation for benchmarking future green sukuk initiatives. To address potential limitations, future research could incorporate real-time performance metrics or additional output variables, such as job creation or social impact, to offer a more holistic assessment of efficiency. Despite these considerations, the application of DEA, combined with the integration of financial and environmental outputs, delivers empirical contributions to the field of sustainable Islamic finance (Alhammadi, 2024; Istaiteyeh *et al*., 2024; Khan *et al*., 2024). This study highlights the transformative potential of green sukuk in advancing the global transition to renewable energy, reinforcing its role as a key instrument in achieving sustainable development objectives.

5. Conclusion

This study provides an analysis of green sukuk as a shariah-compliant financing instrument for renewable energy projects, with a focus on its structural and operational dynamics in Indonesia and Malaysia, two prominent OIC member states. The findings underscore the influence of sukuk structure, specifically contract type and governance mechanisms, on project efficiency and environmental outcomes, though these relationships should be interpreted as contextual associations rather than causal determinants. Green sukuk, as a distinct financial instrument, adheres to shariah principles by prohibiting interest (riba), excessive uncertainty (gharar), and investments in environmentally harmful activities, setting it apart from conventional investment vehicles. Unlike standard investments, which often prioritize short-term financial returns and may involve speculative or environmentally detrimental practices, green sukuk integrates ethical and sustainability considerations, aligning financial objectives with environmental, social, and governance (ESG) criteria. This alignment ensures that funds are channeled into projects that deliver measurable ecological benefits, such as reduced carbon emissions, while maintaining shariah compliance.

Within the selected cases, the comparative analysis suggests that ijarah-based green sukuk, exemplified by Indonesia's state-driven initiatives, appeared to be associated with stronger governance arrangements and more predictable return profiles, making them appear well-suited to large-scale, centralized renewable energy projects such as the 145 MW Cirata PLTS, which achieved a DEA efficiency score of 1.0000. These contracts appeared to support stability in fund allocation and regulatory oversight, which are essential for achieving national energy policy objectives. In contrast, mudharabah based sukuk, as observed in Malaysia's Tadau energy project, appeared to be associated with greater adaptability and private-sector flexibility, enabling the integration of advanced photovoltaic technologies. However, this flexibility also appeared to introduce greater uncertainty in returns, as reflected in its intermediate DEA score of 0.6310, underscoring the importance of enhanced transparency and risk management. The trade-offs between stability and flexibility observed across the selected cases highlight the potential value of hybrid contracts, such as musharakah-murabahah, which may combine the governance predictability of ijarah with the operational adaptability of mudharabah. Such hybrid structures warrant further empirical examination before broader conclusions can be drawn.

For regulators, the findings suggest that a harmonized regulatory framework one that integrates Indonesia's emphasis on compliance and centralized governance with Malaysia's flexible, market-oriented approach may offer a stronger foundation for green sukuk issuance. Policymakers in OIC countries should prioritize governance models that ensure transparency and accountability while remaining open to structural innovation. For investors, green sukuk presents an opportunity to pursue financial returns while contributing to sustainable development goals, distinguishing it from conventional instruments that may overlook ethical or environmental dimensions. The study's integrated efficiency measurement framework, combining cost-effectiveness analysis (CEA) and data envelopment analysis (DEA), provides a replicable and transparent methodology for assessing green sukuk performance at the project level, enabling issuers, regulators, and project developers to better align financing structures with measurable energy and environmental outcomes.

The implications of this research extend beyond Indonesia and Malaysia, offering a reference framework for other OIC member states seeking to design context-sensitive and financially sustainable green sukuk policies aligned with SDG objectives. Given the exploratory and case-based nature of this study, the findings should not be generalized without further empirical validation across a broader set of projects and jurisdictions. Future research should expand the sample of DMUs, incorporate longitudinal performance data, and examine how contractual structures interact with institutional, regulatory, and project-specific conditions in shaping green sukuk effectiveness. Ultimately, this study contributes to the literature by providing exploratory evidence that relative project-level efficiency within the selected cases may be associated with the interaction of sukuk structure, project scale, governance arrangements, and implementation context, rather than with contract type alone. Further research using a larger and more diverse set of projects is required to assess the robustness and generalizability of these observed patterns.

REFERENCES

Abd Aziz, A. J., Baharuddin, N. A., Khalid, R. M., & Kamarudin, S. K. (2024). Review of the policies and development programs for renewable energy in Malaysia: Progress, achievements and challenges. *Energy Exploration & Exploitation*, *42*(4), 1472–1501. https://doi.org/10.1177/01445987241227509

Abdullah, M. S., & Keshminder, J. S. (2022). What drives green sukuk? A leader's perspective. *Journal of Sustainable Finance & Investment*, *12*(3), 985–1005. https://doi.org/10.1080/20430795.2020.1821339

Abubakar, M., & Abdullahi, N. (2019). Sukuk. In *Islamic Corporate Finance* (pp. 136–146). Routledge. https://doi.org/10.4324/9781351061506-7

Ahmad Tajjudin Rozman, N. A. A. (2022). *Green Sukuk , Environmental Issues and Strategy Green Sukuk , Environmental Issues and Strategy*. https://doi.org/10.1088/1755-1315/1067/1/012085

Ahmed, E. R., Islam, M. A., Alabdullah, T. T. Y., & Amran, A. Bin. (2019). A qualitative analysis on the determinants of legitimacy of sukuk. *Journal of Islamic Accounting and Business Research*, *10*(3), 342–368. https://doi.org/10.1108/JIABR-01-2016-0005

Alam, A., Ratnasari, R. T., Jannah, I. L., & Ashfahany, A. E. (2023). "Development and evaluation of Islamic green financing: A systematic review of green sukuk." *Environmental Economics*, *14*(1), 61–72. https://doi.org/10.21511/ee.14(1).2023.06

Alhammadi, S. (2024). Islamic finance as a driver for enhancing economic sustainability and innovation in the GCC. *Journal of Science and Technology Policy Management*. https://doi.org/10.1108/JSTPM-11-2023-0206

Ali, Q., Rusgianto, S., Parveen, S., Yaacob, H., & Zin, R. M. (2023). An empirical study of the effects of green Sukuk spur on economic growth, social development, and financial performance in Indonesia. *Environment, Development and Sustainability*, *26*(8), 21097–21123. https://doi.org/10.1007/s10668-023-03520-6

Ali, Z., & Mawali, A. (2023). The Expansionary Effects of Sukuk in Economic Growth. *2023 International Conference on Sustainable Islamic Business and Finance (SIBF)*, 237–240. https://doi.org/10.1109/SIBF60067.2023.10380027

Alkadi, R. S. (2024). Towards a sustainable future: a comprehensive review of Green Sukuk. *Review of Accounting and Finance*, *23*(4), 467–488. https://doi.org/10.1108/RAF-03-2023-0105

Alnabulsi, K. (2024). Green Finance on Islamic Financial Markets: A Sustainable Approach to Growth. *2024 International Conference on Sustainable*

Islamic Business and Finance (SIBF), 1–4. https://doi.org/10.1109/SIBF63788.2024.10883851

Alsaghir, M. (2023). *Digital risks and Islamic FinTech: a road map to social justice and fi nancial inclusion*. https://doi.org/10.1108/JIABR-10-2022-0262

Amiruddin, A., Dargaville, R., Liebman, A., & Gawler, R. (2024). Integration of Electric Vehicles and Renewable Energy in Indonesia's Electrical Grid. *Energies*, *17*(9), 2037. https://doi.org/10.3390/en17092037

Ardiana, P. A., Diantini, N. N. A., Sudirman, I. M. S. N., Sudana, I. P. G., Putri, N. P. A. W., & Yanthi, K. D. L. (2025). Institutional work in making sustainability reporting mandatory in Indonesia through sustainable finance. *Journal of Accounting in Emerging Economies*, *15*(3), 645–669. https://doi.org/10.1108/JAEE-02-2024-0088

Ari, I., & Isik, M. (2022). *Assessing the Performance of the Developing Countries for the Utilization of the Green Climate Fund*. *4*(February), 1–10. https://doi.org/10.3389/fclim.2022.813406

Ari, I., & Koc, M. (2021). Philanthropic-crowdfunding-partnership: A proof-of-concept study for sustainable financing in low-carbon energy transitions. *Energy*, *222*. https://doi.org/10.1016/j.energy.2021.119925

Azhgaliyeva, D., Kapoor, A., & Liu, Y. (2020). Green bonds for financing renewable energy and energy efficiency in South-East Asia: a review of policies. *Journal of Sustainable Finance & Investment*, *10*(2), 113–140. https://doi.org/10.1080/20430795.2019.1704160

Baal, P. Van, Morton, A., & Severens, J. L. (2018). Social Science & Medicine Health care input constraints and cost e ff ectiveness analysis decision rules. *Social Science & Medicine*, *200*(January), 59–64. https://doi.org/10.1016/j.socscimed.2018.01.026

Balakrishnan, P. (2025). *Global Renewable Energy Transition Challenges and Strategic Solutions* (pp. 63–96). https://doi.org/10.4018/979-8-3693-8814-3.ch003

Basri, N. A., Ramli, A. T., & Aliyu, A. S. (2015). Malaysia energy strategy towards sustainability: A panoramic overview of the benefits and challenges. *Renewable and Sustainable Energy Reviews*, *42*, 1094–1105. https://doi.org/10.1016/j.rser.2014.10.056

Bojke, L., Manca, A., Asaria, M., Mahon, R., Ren, S., & Palmer, S. (2017). How to Appropriately Extrapolate Costs and Utilities in Cost-Effectiveness Analysis. *PharmacoEconomics*, *35*(8), 767–776. https://doi.org/10.1007/s40273-017-0512-6

Bojke, L., Schmitt, L., Lomas, J., Richardson, G., & Weatherly, H. (2018). Economic Evaluation of Environmental Interventions: Reflections on Methodological Challenges and Developments. *International Journal of Environmental Research and Public Health*, *15*(11), 2459. https://doi.org/10.3390/ijerph15112459

Buttigieg, C. P., & Pulis, S. (2024). Strategic initiatives to address greenwashing. *ERA Forum*, 327–337. https://doi.org/10.1007/s12027-024-00815-7

Camba, A., Lim, G., & Gallagher, K. (2022). Leading sector and dual economy: how Indonesia and Malaysia mobilised Chinese capital in mineral processing. *Third World Quarterly*, *43*(10), 2375–2395. https://doi.org/10.1080/01436597.2022.2093180

Chaudhuri, R., & Vrontis, D. (2025). *Assessing the economic and social impacts of greenwashing: moderating*. *1*. https://doi.org/10.1108/IJBM-07-2024-0440

Citalingam, K., & Go, Y. I. (2022). Hybrid energy storage design and dispatch strategy evaluation with sensitivity analysis: <scp>Techno-economic-environmental</scp> assessment. *Energy Storage*, *4*(5). https://doi.org/10.1002/est2.353

Coelli, T. J. (1995). RECENT DEVELOPMENTS IN FRONTIER MODELLING AND EFFICIENCY MEASUREMENT. *Australian Journal of Agricultural Economics*, *39*(3), 219–245. https://doi.org/10.1111/j.1467-8489.1995.tb00552.x

Cooper, W. W., Li, S., Seiford, L. M., & Zhu, J. (2011). *Sensitivity Analysis in DEA* (pp. 71–91). https://doi.org/10.1007/978-1-4419-6151-8_3

Cooper, W. W., Seiford, L. M., & Zhu, J. (2011). *Data Envelopment Analysis: History, Models, and Interpretations* (pp. 1–39). https://doi.org/10.1007/978-1-4419-6151-8_1

Criollo, A., Minchala-Avila, L. I., Benavides, D., Ochoa-Correa, D., Tostado-Véliz, M., Meteab, W. K., & Jurado, F. (2024). Green hydrogen production: Fidelity in simulation models for technical–economic analysis. *International Journal of Hydrogen Energy*, *67*, 1–26. https://doi.org/10.1016/j.ijhydene.2024.04.134

Dar, Q. F., Ahn, Y., & Dar, G. F. (2021). Evaluation and investigation: the determinants of central banking efficiency. *Pakistan Journal of Humanities and Social Sciences*, *9*(3), 481–493. https://doi.org/10.52131/pjhss.2021.0903.0181

Delgado-von-eitzen, C., Anido-rif, L., & Fern, M. J. (2021). *applied sciences Application of Blockchain in Education: GDPR-Compliant and Scalable Certification and Verification of Academic Information*.

Dellnitz, A., Tavana, M., & Banker, R. (2023). A novel median-based optimization model for eco-efficiency assessment in data envelopment analysis. *Annals of Operations Research*, *322*(2), 661–690. https://doi.org/10.1007/s10479-022-04937-4

Donastorg, A. D., Renukappa, S., & Suresh, S. (2022). Financing renewable energy projects in the Dominican Republic: an empirical study. *International Journal of Energy Sector Management*, *16*(1), 95–111. https://doi.org/10.1108/IJESM-10-2020-0002

Dong, H., Zhang, L., & Zheng, H. (2024). Green bonds: Fueling green innovation or just a fad? *Energy Economics*, *135*, 107660. https://doi.org/10.1016/j.eneco.2024.107660

Endri, E., & Hania, B. T. (2022). *Corporate green Sukuk issuance for sustainable financing in Indonesia*. https://doi.org/10.21511/ee.13(1).2022.04

Fadhzana, N., & Noor, M. (2024). *Shariah non-compliance risk and its management techniques: empirical evidences in selected wakalah sukuk documents issued in Malaysia jurisdiction*. *16*(4), 803–829. https://doi.org/10.1108/QRFM-10-2022-0171

Fan, M., Yang, P., & Li, Q. (2022). Impact of environmental regulation on green total factor productivity: a new perspective of green technological innovation. *Environmental Science and Pollution Research*, *2018*, 53785–53800. https://doi.org/10.1007/s11356-022-19576-2

Feng, C., Chu, F., Ding, J., Bi, G., & Liang, L. (2015). Carbon Emissions Abatement (CEA) allocation and compensation schemes based on DEA. *Omega*, *53*, 78–89. https://doi.org/10.1016/j.omega.2014.12.005

Firoozi, A. A., Tshambane, M., Firoozi, A. A., & Sheikh, S. M. (2024). Strategic load management: Enhancing eco-efficiency in mining operations through automated technologies. *Results in Engineering*, *24*, 102890. https://doi.org/10.1016/j.rineng.2024.102890

Ghaemi Asl, M., Rashidi, M. M., Tiwari, A. K., Lee, C.-C., & Roubaud, D. (2023). Green bond vs. Islamic bond: Which one is more environmentally friendly? *Journal of Environmental Management*, *345*, 118580. https://doi.org/10.1016/j.jenvman.2023.118580

Ghardallou, W., & Abaalkhail, L. (2024). *The Moderating Effect of Institutions on the Relationship between Financial Development and Environmental Quality: Evidence from GCC countries*. *83*(August), 836–844. https://doi.org/10.56042/jsir.v83i8.8926

Gundogdu, A. S. (2019). Determinants of Success in Islamic Public-Private Partnership Projects (PPPs) in the Context of SDGs. *Turkish Journal of Islamic Economics*, *6*(2), 25–43. https://doi.org/10.26414/A055

Harahap, B., Risfandy, T., & Futri, I. N. (2023). Islamic Law, Islamic Finance, and Sustainable Development Goals: A Systematic Literature Review. *Sustainability*, *15*(8), 6626. https://doi.org/10.3390/su15086626

Hassan, Q., Viktor, P., J. Al-Musawi, T., Mahmood Ali, B., Algburi, S., Alzoubi, H. M., Khudhair Al-Jiboory, A., Zuhair Sameen, A., Salman, H. M., & Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. *Renewable Energy Focus*, *48*, 100545. https://doi.org/10.1016/j.ref.2024.100545

Hassanpour, M. (2020). *EVALUATION OF IRANIAN SMALL AND MEDIUM-SIZED INDUSTRIES USING THE DEA BASED ON ADDITIVE RATIO MODEL – A REVIEW Malek Hassanpour*. *18*, 491–511.

Hermoso-Orzáez, M. J., García-Alguacil, M., Terrados-Cepeda, J., & Brito, P. (2020). Measurement of environmental efficiency in the countries of the European Union with the enhanced data envelopment analysis method (DEA) during the period 2005–2012. *Environmental Science and Pollution Research*, *27*(13), 15691–15715. https://doi.org/10.1007/s11356-020-08029-3

Higgins, A. M., & Harris, A. H. (2012). Health Economic Methods: Cost-Minimization, Cost-Effectiveness, Cost-Utility, and Cost-Benefit Evaluations. *Critical Care Clinics*, *28*(1), 11–24. https://doi.org/10.1016/j.ccc.2011.10.002

Hilali, H., Hovelaque, V., & Giard, V. (2023). Integrated scheduling of a multi-site mining supply chain with blending, alternative routings and co-production. *International Journal of Production Research*, *61*(6), 1829–1848. https://doi.org/10.1080/00207543.2022.2049909

Ibrahim, M. H. (2015). Issues in Islamic banking and finance: Islamic banks, Shari'ah-compliant investment and sukuk. *Pacific-Basin Finance Journal*, *34*, 185–191. https://doi.org/10.1016/j.pacfin.2015.06.002

Iqbal Balative, M., Hariyanto, E., Sholikhah, A., & Gigih Prayoga, R. (2025). A Closer Look at Indonesia's Experience in Developing Green Sukuk. In *Islamic Finance and Sustainability* (pp. 441–464). Routledge. https://doi.org/10.4324/9781003518617-23

Irfany, M. I., Utami, A. D., Lubis, D., Ramadhini, F., Suwari, L. F., Maula, N. R., Fitriyatustany, F., & Haq, D. A. (2024). Islamic Finance and Environmental Sustainability: Empirical Insight from OIC Countries. *International Journal of Energy Economics and Policy*, *14*(6), 707–715. https://doi.org/10.32479/ijeep.17400

Istaiteyeh, R., Milhem, M. M., & Elsayed, A. (2024). Efficiency Assessment and Determinants of Performance: A Study of Jordan's Banks Using DEA and Tobit Regression. *Economies*, *12*(2), 37. https://doi.org/10.3390/economies12020037

Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using Mixed-Methods

Sequential Explanatory Design: From Theory to Practice. ***Field Methods***, ***18***(1), 3–20. https://doi.org/10.1177/1525822X05282260

Kachkar, O., & Al Fares, M. (2024). ***Sri Sukuk to Achieve SDGs with a Special Reference to the Legal and Regulatory Framework in Malaysia*** (pp. 159–184). https://doi.org/10.1007/978-3-031-61778-2_9

Kang, D., & Sohn, S. Y. (2024). Green efficiency strategy considering cyclical relationships among CO2 emissions, green patents, and green bonds. ***Journal of Cleaner Production***, ***464***, 142704. https://doi.org/10.1016/j.jclepro.2024.142704

Karim, R. (2023). Prospects and challenges of Islamic finance instruments for low-carbon energy transitions: a legal analysis from an energy justice perspective. ***Journal of Energy & Natural Resources Law***, ***41***(2), 195–209. https://doi.org/10.1080/02646811.2023.2187550

Keshminder, J. S., Abdullah, M. S., & Mardi, M. (2022). Green sukuk – Malaysia surviving the bumpy road: performance, challenges and reconciled issuance framework. ***Qualitative Research in Financial Markets***, ***14***(1), 76–94. https://doi.org/10.1108/QRFM-04-2021-0049

Khalili, S., Lopez, G., & Breyer, C. (2025). Role and trends of flexibility options in 100 % renewable energy system analyses towards the Power-to-X Economy. ***Renewable and Sustainable Energy Reviews***, ***212***(June 2024), 115383. https://doi.org/10.1016/j.rser.2025.115383

Khan, A., Rabbani, M. R., Aljalahma, R., Tabassum, S., & Al-Hiyari, A. (2024). Demystifying the Trade-Off Debate in Financial Sustainability and Social Outreach and Ranking of Indian MFIs: A Bootstrap DEA Framework. ***Asia-Pacific Financial Markets***. https://doi.org/10.1007/s10690-024-09488-1

Kuanova, L. (2025). ***Research trends in Sukuk studies: A bibliometric analysis of global academic publications***. https://doi.org/10.21511/imfi.22(2).2025.27

Kumar, C. (2021). Public Performance & Management Review Impact of Contract Choice on the Public-Private Partnerships ' Performance: A Tale of Two Contracts Impact of Contract Choice on the Public-Private Partnerships ' Performance: A Tale of Two Contracts. ***Public Performance & Management Review***, ***44***(6), 1239–1267. https://doi.org/10.1080/15309576.2021.1985537

Kusnawirawan, I., Syarkani, Y., Hernayati, H., & Waluyo, I. (2025). Safeguarding Investor Rights: OJK's Regulatory Framework Including Management and Challenges in Indonesia's Capital Market. ***Jurnal Multidisiplin Indonesia***, ***4***(3), 193–201. https://doi.org/10.58344/jmi.v4i3.2243

Li, C., Sampene, A. K., Agyeman, F. O., Brenya, R., & Wiredu, J. (2022). The role of green finance and energy innovation in neutralizing environmental pollution: Empirical evidence from the MINT economies. *Journal of Environmental Management*, *317*. https://doi.org/10.1016/j.jenvman.2022.115500

Li, S., Zhang, M., Hou, L., Gong, B., & Chen, K. (2024). A framework for cost-effectiveness analysis of greenhouse gas mitigation measures in dairy industry with an application to dairy farms in China. *Journal of Environmental Management*, *370*, 122521. https://doi.org/10.1016/j.jenvman.2024.122521

Liu, D., Chang, Y., Yao, H., & Kang, Y. (2023). *The impact of green fi nance on green economy development ef fi ciency: based on panel data of 30 provinces in China*. *November*, 1–15. https://doi.org/10.3389/fenvs.2023.1328914

Liu, F. H. M., & Lai, K. P. Y. (2021). *Ecologies of green fi nance: Green sukuk and development of green Islamic fi nance in Malaysia*. *53*(8), 1896–1914. https://doi.org/10.1177/0308518X211038349

Lokuwaduge, C. S. D. S., & Silva, K. M. De. (2022). *ESG Risk Disclosure and the Risk of Green Washing*. *16*(1), 146–159.

Luo, Y., & Chen, Y. (2024). How does contractual governance affect construction project performance? The mediating role of the contractor ' s behavior. *Journal of Asian Architecture and Building Engineering*, *00*(00), 1–19. https://doi.org/10.1080/13467581.2024.2396606

Ma, X., Zeng, B., Zhang, Y., Li, Y., & Liu, Z. (2015). Comprehensive Evaluation of Renewable Energy for Power Projects Based on CA-DEA Model. *2015 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*, *3*, 1848–1853. https://doi.org/10.1109/DRPT.2015.7432548

Mahama, A. J., & Yakubu, I. N. (2025). *Islamic Banks' Investment in Green Sukuk and Sustainable Development in the UAE* (pp. 87–100). https://doi.org/10.1007/978-3-031-80744-2_5

Mahomed, Z. (2024). *Sustainable and responsible investment (SRI) Sukuk: lessons from Khazanah ' s Sukuk Ihsan*. *17*(6), 1065–1081. https://doi.org/10.1108/IMEFM-05-2024-0219

Malek, R., Yang, Q., & Dhelim, S. (2024). Toward Sustainable Global Product Development Performance: Exploring the Criticality of Organizational Factors and the Moderating Influence of Global Innovation Culture. *Sustainability*, *16*(10), 3911. https://doi.org/10.3390/su16103911

Maulidia, M., Dargusch, P., Ashworth, P., & Ardiansyah, F. (2019). Rethinking renewable energy targets and electricity sector reform in Indonesia: A private sector perspective. *Renewable and Sustainable Energy Reviews*, *101*, 231–247.

https://doi.org/10.1016/j.rser.2018.11.005

Mohamed Yusoff, N. Y., Ridzuan, A. R., Soseco, T., Wahjoedi, Narmaditya, B. S., & Ann, L. C. (2023). Comprehensive Outlook on Macroeconomic Determinants for Renewable Energy in Malaysia. ***Sustainability***, ***15***(5), 3891. https://doi.org/10.3390/su15053891

Morea, D., & Poggi, L. A. (2017). An innovative model for the sustainability of investments in the wind energy sector: The use of green sukuk in an Italian case study. *International Journal of Energy Economics and Policy*, *7*(2), 53–60. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85017593750&partnerID=40&md5=38ade31baf03c4636c12c4b06d2cd954

Morshed, A. (2025). ***Sustainable energy revolution: green fi nance as the key to the Arab Gulf States ' future***. https://doi.org/10.1108/IJESM-10-2024-0007

Moxey, A., Smyth, M., Taylor, E., Williams, A. P., Centre, C. C., & Dg, K. (2021). Land Use Policy Barriers and opportunities facing the UK Peatland Code: A case-study of blended green finance. ***Land Use Policy***, ***108***(June), 105594. https://doi.org/10.1016/j.landusepol.2021.105594

Kasim, N., Htay, S. N. N., & Salman, S. A. (2014). Proposed approach for best practices of Shari'ah corporate governance in the Malaysian Islamic capital market. ***Research Journal of Applied Sciences, Engineering and Technology***, ***8***(20), 2146–2149. https://doi.org/10.19026/rjaset.8.1211

Nguyen, H. T., Hang, M., & Truong, C. (2023). Journal of Behavioral and Experimental Finance Leadership in a pandemic: Do more able managers keep firms out of trouble? . ***Journal of Behavioral and Experimental Finance***, ***37***, 100781. https://doi.org/10.1016/j.jbef.2022.100781

Niyazbekova, S., Akmatova, A., Karabaeva, K., Osmonova, A., & Mirzaeva, A. (2024). Instruments for financing environmental projects during the global energy transition. ***International Journal of Energy Economics and Policy***, ***14***(6), 1495–1500. https://doi.org/10.32479/ijeep.17166

Noordin, N. H., & Haron, S. N. (2018). ***Complying with the requirements for issuance of SRI sukuk: the case of Khazanah ' s Sukuk Ihsan***. ***9***(3), 415–433. https://doi.org/10.1108/JIABR-02-2016-0024

Norgren, E., & Stankeviciene, J. (2024). Systematic literature review on the methodological approaches of the efficiency of green investment in renewable energy-based development. ***Journal of Sustainable Finance & Investment***, ***14***(1), 30–46. https://doi.org/10.1080/20430795.2022.2081403

Nurzahira, S., Tahrim, C., Muhammad, M. Z., Syakir, M., Rosdi, M., Nor, M., & Yusoff, H. (2019). ***The Revival of Mudharabah Contract: A Proposed Framework***. ***10***(2), 70–73. https://doi.org/10.5430/rwe.v10n2p70

Okpalajiaku, C. C., & Harcourt, P. (2021). The economic prospects for renewable energy investment in Nigeria . *2021 IEEE PES/IAS PowerAfrica*, 1–5. https://doi.org/10.1109/PowerAfrica52236.2021.9543439

Pirgaip, B., & Arslan-Ayaydin, O. (2024). Exploring the greenium in the green Sukuk universe: evidence from the primary market. *International Journal of Islamic and Middle Eastern Finance and Management*, *17*(3), 423–440. https://doi.org/10.1108/IMEFM-05-2023-0186

Putri, R. W., Putri, Y. M., Davey, O., & Sabatira, F. (2023). *GREEN BONDS IN INDONESIA: SYNERGY BETWEEN BANK INDONESIA AND*. *2*(2), 199–220.

Raeni, R., Thomson, I., & Frandsen, A.-C. (2022). Mobilising Islamic Funds for Climate Actions: From Transparency to Traceability. *Social and Environmental Accountability Journal*, *42*(1–2), 38–62. https://doi.org/10.1080/0969160X.2022.2066553

Rahim, R., Rabbani, M. R., Rathore, H. S., & Alam, M. N. (2024). Maqasid Al-Shariah and Green Finance: A Theoretical Framework on Islamic Finance with Sustainable Development Goals for a Greener Future. *2024 International Conference on Sustainable Islamic Business and Finance (SIBF)*, 255–261. https://doi.org/10.1109/SIBF63788.2024.10883847

Rao, H., Chen, D., Shen, F., & Shen, Y. (2022). Can green bonds stimulate green innovation in enterprises? Evidence from China. *Sustainability*, *14*(23), 15631. https://doi.org/10.3390/su142315631

Rao, T., & Mustapa, S. I. (2021). A review of climate economic models in Malaysia. *Renewable and Sustainable Energy Reviews*, *136*, 110395. https://doi.org/10.1016/j.rser.2020.110395

Rifansyah, M., & Hakam, D. F. (2024). Techno economic study of floating solar photovoltaic project in Indonesia using RETscreen. *Cleaner Energy Systems*, *9*, 100155. https://doi.org/10.1016/j.cles.2024.100155

Rose, P. (2025). Corporate sustainable finance. *Law and Political Economy Project*, *6*(0), 1–35. https://doi.org/10.5070/LP60065155

Rozman, A. T., & Azmi, and N. A. (2022). *Green Sukuk , Environmental Issues and Strategy Green Sukuk , Environmental Issues and Strategy*. https://doi.org/10.1088/1755-1315/1067/1/012085

Ruan, W., Guo, Z., Yang, J., Gao, L., Dong, Y., & Liu, Q. (2024). Assessing the progress toward achieving energy and climaterelated sustainable development goals under four global energy transition outlooks. *Sustainable Development*, *32*(4), 3695–3707. https://doi.org/10.1002/sd.2873

Rusydiana, A. S., & Rosadhillah, V. K. (2025). *Ef fi ciency of renewable energy for sustainable development: empirical evidence in OIC countries*. https://doi.org/10.1108/IJESM-09-2024-0055

Sajjad, S., Bhuiyan, R. A., Dwyer, R. J., Bashir, A., & Zhang, C. (2024). Balancing prosperity and sustainability: unraveling financial risks and green finance through a COP27 lens. *Studies in Economics and Finance*, *41*(3), 545–570. https://doi.org/10.1108/SEF-06-2023-0353

Sealey, C. W., & Lindley, J. T. (1977). INPUTS, OUTPUTS, AND A THEORY OF PRODUCTION AND COST AT DEPOSITORY FINANCIAL INSTITUTIONS. *The Journal of Finance*, *32*(4), 1251–1266. https://doi.org/10.1111/j.1540-6261.1977.tb03324.x

Setiawan, R. A., & Suwandaru, A. (2024). Risk of Islamic securities (SUKUK) and a proposed reforms for development: the Indonesian experience. *Journal of Sustainable Finance & Investment*, *0795*, 1–20. https://doi.org/10.1080/20430795.2024.2337359

Setiawan, R. adetio. (2024). *THE FUTURE OF ISLAMIC BANKING AND FINANCE*.

Setyowati, A. B. (2023). Governing sustainable finance: insights from Indonesia. *Climate Policy*, *23*(1), 108–121. https://doi.org/10.1080/14693062.2020.1858741

Shahrul, M., & Ishak, I. (2021). *Equity-based Islamic crowdfunding in Malaysia: a potential application for mudharabah*. *13*(2), 183–198. https://doi.org/10.1108/QRFM-03-2020-0024

Shahrul, M., Ishak, I., Aderemi, A. M. R., Kamaruzaman, N. R., & Mahyudin, M. I. (2025). *Mudharabah instrument via an integrated waqf – equity crowdfunding model for sustainable blended financing in malaysia*. *30*(2).

Sneideriene, A., & Legenzova, R. (2025). Research in International Business and Finance Greenwashing prevention in environmental , social , and governance (ESG) disclosures: A bibliometric analysis. *Research in International Business and Finance*, *74*, 102720. https://doi.org/10.1016/j.ribaf.2024.102720

Suaidi, S. (2025). Bridging Institutional and Regulatory Gaps: Enhancing Sharia Compliance in Islamic Financial Institutions in Indonesia. *El-Uqud: Jurnal Kajian Hukum Ekonomi Syariah*, *3*(1), 23–39. https://doi.org/10.24090/eluqud.v3i1.13288

Surachman, E. N., Hermawan, R. P., Handayani, D., & Astuti, E. (2022). *Evaluation of Sovereign Sukuk as a government fi nancing instrument with stakeholder theory: a moving forward policy from Indonesia ' s experience*. *14*(2), 315–338. https://doi.org/10.1108/JIABR-03-2022-0066

Tan, K. M., Kamarudin, F., Bany-ariffin, A. N., & Rahim, N. A. (2013). *Investigation on firm efficiency: evidence from selected Asia-Pacific countries*. *1957*. https://doi.org/10.1108/BIJ-06-2017-0145

Testa, F., Iraldo, F., & Frey, M. (2011). *Environmental regulation and competitive performance: new evidence from a sectoral study Environmental regulation and competitive performance: new evidence from a sectoral study*. *4509*. https://doi.org/10.1080/13504509.2011.578678

Thomas, G., Demski, C., & Pidgeon, N. (2020). Energy Research & Social Science Energy justice discourses in citizen deliberations on systems fl exibility in the United Kingdom: Vulnerability , compensation and empowerment. *Energy Research & Social Science*, *66*(May 2019), 101494. https://doi.org/10.1016/j.erss.2020.101494

Torabi, S. A., & Hassini, E. (2009). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: an interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19), 5475–5499. https://doi.org/10.1080/00207540801905460

Tsolas, I. E. (2020). Benchmarking wind farm projects by means of series two-stage DEA. *Clean Technologies*, *2*(3), 365–376. https://doi.org/10.3390/cleantechnol2030022

Ulfah, I. F., Sukmana, R., & Laila, N. (2024). *A structured literature review on green sukuk (Islamic bonds): implications for government policy and future studies*. 1118–1133. https://doi.org/10.1108/JIABR-10-2022-0255

Ulfah, I. F., Sukmana, R., Laila, N., & Sulaeman, S. (2024). A structured literature review on green sukuk (Islamic bonds): implications for government policy and future studies. *Journal of Islamic Accounting and Business Research*, *15*(7), 1118–1133. https://doi.org/10.1108/JIABR-10-2022-0255

Utami, D. E. (2025). *Three-way interaction moderation model of legal origin in strengthening the role of fi rm characteristics in choice of sukuk type*. *16*(2), 305–320. https://doi.org/10.1108/JIABR-11-2022-0308

De Villiers, A., & Vermeulen, H. J. (2017). Sector performance monitoring in utility-scale solar farms using data envelopment analysis. *Proceedings of the Southern African Universities Power Engineering Conference (SAUPEC)*, 192–197.

Vitti, M., Facchini, F., & Mummolo, G. (2024). Assessing the decarbonisation potential of waste-to-hydrogen routes in the energy transition phase: An environmental analytical model. *Journal of Cleaner Production*, *457*(April), 142345. https://doi.org/10.1016/j.jclepro.2024.142345

Voudouris, I., Lioukas, S., Iatrelli, M., & Caloghirou, Y. (2012). Effectiveness of technology investment: Impact of internal technological capability, networking and investment's strategic importance. *Technovation*, *32*(6), 400–414. https://doi.org/10.1016/j.technovation.2012.04.001

Vyas, G. S., & Jha, K. N. (2017). Benchmarking green building attributes to achieve cost effectiveness using a data envelopment analysis. *Sustainable Cities and Society*, *28*, 127–134. https://doi.org/10.1016/j.scs.2016.08.028

Wang, L.-W., Le, K.-D., & Nguyen, T.-D. (2019). Assessment of the Energy Efficiency Improvement of Twenty-Five Countries: A DEA Approach. *Energies*, *12*(8), 1535. https://doi.org/10.3390/en12081535

Wang, R., Duan, Y., & Li, D. (2025). Beyond scale to efficiency: a dual - perspective framework for green finance in China. In *Discover Sustainability*. Springer International Publishing. https://doi.org/10.1007/s43621-025-01354-y

Wang, S., Sun, L., & Iqbal, S. (2022). Green financing role on renewable energy dependence and energy transition in E7 economies. *Renewable Energy*, *200*, 1561 – 1572. https://doi.org/10.1016/j.renene.2022.10.067

Wang, Z., & Wang, X. (2022). Research on the impact of green finance on energy efficiency in different regions of China based on the DEA-Tobit model. *Resources Policy*, *77*, 102695. https://doi.org/10.1016/j.resourpol.2022.102695

Warren, P. (2019). The role of climate finance beyond renewables: demand-side management and carbon capture, usage and storage. *Climate Policy*, *19*(7), 861 – 877. https://doi.org/10.1080/14693062.2019.1605330

Wing, C., & Zhong, J. (2015). *Construction of a responsible investment composite index for renewable energy industry*. *51*, 288–303. https://doi.org/10.1016/j.rser.2015.05.071

Zain, N. S. (2020). *An exploratory study on Musharakah SRI Sukuk for the development of Waqf properties / assets in Malaysia*. *12*(3), 301–314. https://doi.org/10.1108/QRFM-09-2018-0099

Zanou, B., Bellas, C., & Skourtos, M. (2010). Implementation of the European Water Framework Directive: procedures and a simple model for the identification of the most cost-effective measures in eutrophicated catchments. *Water Policy*, *12*(3), 369–380. https://doi.org/10.2166/wp.2009.120

Zhang, J., Yang, G., Ding, X., & Qin, J. (2024). Can green bonds empower green technology innovation of enterprises? *Environmental Science and Pollution Research*, *31*(7), 10032–10044. https://doi.org/10.1007/s11356-022-23192-5

Zhang, K.-C., Safi, A., Kchouri, B., Banerjee, A., & Wang, L. (2024). The three greens: Innovation, finance, and taxes—Performance analysis and future implications. *Journal of Innovation and Knowledge*, *9*(4). https://doi.org/10.1016/j.

jik.2024.100627

Zhang, X., Liu, W., Feng, Q., & Zeng, J. (2024). Multi-objective optimization of the spatial layout of green infrastructures with cost-effectiveness analysis under climate change scenarios. *Science of The Total Environment*, *948*, 174851. https://doi.org/10.1016/j.scitotenv.2024.174851

Zhu, C., Xi, X., & Goh, M. (2024). Differential game analysis of joint emission reduction decisions under mixed carbon policies and CEA. *Journal of Environmental Management*, *358*, 120913. https://doi.org/10.1016/j.jenvman.2024.120913