

Optimizing Cash Waqf and Waqf Asset Development for Sustainable Socio-Economic Growth: Integrating Islamic Financial Institutions, Sukuk, and Social Entrepreneurship Models

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ABSTRACT

The review focuses on key themes including cash waqf innovation, governance quality, Islamic financial intermediation, waqf investment, and socio-economic sustainability. The findings reveal that modern waqf has evolved from a traditional philanthropic instrument into a strategic development financing tool capable of supporting large-scale social, economic, and environmental projects. The integration of Islamic banking and capital market instruments such as Cash Waqf Linked Sukuk significantly improves financial efficiency, transparency, and scalability of waqf. Furthermore, the incorporation of social entrepreneurship transforms waqf into a productive and self-sustaining economic system that empowers beneficiaries and reduces long-term dependency. The study concludes that an integrated waqf ecosystem combining financial institutions, investment mechanisms, and entrepreneurial models is essential for maximizing the socio-economic impact of waqf and achieving sustainable development goals. The results provide important implications for policymakers, waqf authorities, and Islamic financial institutions in designing more effective and inclusive waqf frameworks.

INTRODUCTION

Waqf is a unique Islamic social finance instrument that provides long-term social and economic benefits through perpetual asset dedication. It has historically supported education, healthcare, and poverty alleviation across Muslim societies. Modern scholarship views waqf as a mechanism for sustainable wealth redistribution. The socio-economic role of waqf is increasingly relevant in the era of inequality and financial exclusion. Recent studies confirm that waqf remains a key pillar of Islamic social finance (Ali & Hasan, 2023; Ahmad & Rahman, 2023).

Despite its potential, many waqf systems remain inefficient due to weak governance and lack of performance measurement. In Indonesia, this problem led to the development of a National Waqf Index. This index helps evaluate institutional performance, governance quality, and asset utilization. It also supports policy decisions and transparency. Ahmad and Rahman (2023) demonstrate that standardized measurement significantly improves waqf accountability.

Cash waqf has emerged as a flexible alternative to traditional land-based waqf. It allows wider participation from the public, including small donors. Cash waqf can be invested to generate sustainable returns for social programs. Its adaptability makes it compatible with modern financial systems. Hassan and Abdullah (2024) show that cash waqf innovation enhances the economic impact of waqf institutions.

Islamic financial institutions play a central role in managing and channeling cash waqf. Banks provide custodianship, investment platforms, and governance structures. This integration strengthens both financial stability and social outreach. It also aligns waqf with financial inclusion objectives. Hidayat and Wahyudi (2024) confirm that Sharia banks significantly improve the effectiveness of money waqf management.

Social entrepreneurship has become an important mechanism for transforming waqf into productive capital. Through entrepreneurial projects, waqf funds can support micro-enterprises and community development. This approach moves waqf beyond charity into sustainable empowerment. It also ensures continuous benefit for beneficiaries. Rahman and Yusof (2024) demonstrate that social entrepreneurship models enhance the sustainability of cash waqf programs.

Waqf investment funds further expand the economic potential of waqf assets. These funds allow diversification across sectors such as health, education, and infrastructure. Professional fund management increases returns while maintaining Sharia compliance. This model strengthens the financial sustainability of waqf. Aziz and Zainal (2025) find that waqf investment funds significantly improve socio-economic outcomes.

Waqf is also increasingly linked to environmental and climate-related development goals. Modern waqf instruments can finance renewable energy, green housing, and climate adaptation. This aligns Islamic finance with global sustainability agendas. Such integration increases waqf relevance in

contemporary policy frameworks. Khan and Ahmed (2025) show that waqf and zakat can support climate-resilient community development.

Agricultural waqf has also gained renewed attention as a tool for land consolidation and food security. Fragmented land ownership limits productivity in many Muslim countries. Waqf provides a mechanism to preserve land for productive use. This strengthens rural economies and reduces poverty. El-Gohary and Salama (2024) prove that waqf can mitigate agricultural land fragmentation.

The development of waqf land requires strong institutional and managerial capacity. Poor project planning often results in underutilized waqf assets. Strategic development frameworks are therefore essential. Professional management increases asset productivity. Rahim and Omar (2025) identify governance quality as a critical success factor in waqf land development.

Cash waqf linked sukuk represents a major financial innovation in Islamic social finance. It integrates charitable capital with capital market instruments. This allows waqf to finance large-scale social infrastructure. The model increases both impact and financial sustainability. Sulaiman and Ismail (2025) demonstrate that CWLS overcomes key barriers in waqf financing.

However, many countries still face barriers in optimizing cash waqf systems. These include regulatory gaps, lack of expertise, and limited public awareness. Overcoming these challenges requires institutional reform and financial innovation. Stronger governance frameworks are essential. Hassan and Abdullah (2024) and Ahmad and Rahman (2023) both emphasize governance as a key success factor.

Overall, modern waqf is evolving into a comprehensive socio-economic development tool. It integrates financial institutions, investment funds, sukuk, and social enterprises. This transformation strengthens waqf's role in achieving sustainable development. Academic evidence supports this multidimensional approach. The convergence of these models forms the foundation of a new paradigm in Islamic social finance (Ali & Hasan, 2023; Aziz & Zainal, 2025; Khan & Ahmed, 2025).

THEORETICAL REVIEW

Waqf as an Islamic Social Finance Instrument

Waqf is a permanent charitable endowment in Islamic law, where the principal asset is preserved while its benefits are distributed for public welfare. From the perspective of Islamic economics, waqf functions as a long-term redistribution mechanism that transforms private wealth into social capital. Unlike zakat and charity, waqf creates sustainable streams of social benefits across generations. Ali and Hasan (2023) argue that waqf balances wealth accumulation and distribution in Islamic societies. Ahmad and Rahman (2023) further confirm that waqf has evolved into a core pillar of modern Islamic social finance. Waqf is theoretically aligned with the objectives of *maqasid al-shariah*, especially the protection of wealth, life, and social welfare. By transforming idle assets into productive resources, waqf contributes to poverty alleviation and

economic inclusion. Therefore, waqf is not merely a religious obligation but also an economic development instrument.

Cash Waqf and Financial Intermediation Theory

Cash waqf refers to the endowment of money that is invested in Shariah-compliant activities, where only the returns are distributed to beneficiaries. From the perspective of financial intermediation theory, Islamic financial institutions act as intermediaries between donors (waqif) and productive investments. These institutions mobilize idle cash waqf into income-generating projects. Hassan and Abdullah (2024) show that cash waqf innovation improves efficiency and sustainability of waqf management. Hidayat and Wahyudi (2024) also demonstrate that Islamic banks enhance transparency, governance, and financial discipline in cash waqf management. Through this intermediation process, cash waqf becomes a dynamic financial resource rather than a passive donation. It enables waqf to support long-term socio-economic programs.

Waqf Governance Theory

Governance theory emphasizes accountability, transparency, and institutional integrity in managing entrusted assets. In waqf institutions, the nazhir (waqf manager) serves as a trustee responsible for preserving and growing waqf assets. Weak governance leads to mismanagement, idle assets, and loss of public trust. Ahmad and Rahman (2023) highlight that performance measurement systems such as the National Waqf Index are essential to improve governance quality. Strong governance frameworks increase donor confidence and investment efficiency. Therefore, governance quality is a fundamental determinant of waqf sustainability and socio-economic impact.

Waqf Investment and Sustainability Theory

Investment theory states that professionally managed funds can maximize returns while minimizing risks. When applied to waqf, this theory supports the creation of waqf investment funds that allocate waqf assets into productive and Shariah-compliant ventures. Aziz and Zainal (2025) find that waqf investment funds significantly contribute to social welfare and sustainable development. These investments generate stable income streams for education, healthcare, and poverty alleviation programs. This aligns waqf with Sustainable Development Goals (SDGs) by creating long-term economic and social value.

Cash Waqf Linked Sukuk (CWLS) Theory

Cash Waqf Linked Sukuk integrates Islamic capital market instruments with waqf principles. Sukuk serve as investment vehicles, while cash waqf provides social capital. From the perspective of *blended finance theory*, CWLS combines philanthropic and commercial capital to achieve both financial sustainability and social impact. Sulaiman and Ismail (2025) demonstrate that CWLS overcomes funding constraints in large-scale social infrastructure projects. This makes waqf a strategic financing tool for hospitals, schools, and social housing.

Social Entrepreneurship Theory in Waqf

Social entrepreneurship theory explains how organizations can generate social value through business-based solutions. In waqf, funds are used to create income-generating enterprises whose profits benefit beneficiaries. Rahman and Yusof (2024) show that social entrepreneurship models significantly improve the sustainability of cash waqf programs. This approach transforms waqf from a passive charity into an active development engine. It enhances economic empowerment, employment, and financial independence among beneficiaries.

Integrated Waqf Development Model

The integration of cash waqf, Islamic banking, sukuk, investment funds, and social entrepreneurship forms a comprehensive waqf ecosystem. This integrated model maximizes both financial efficiency and social impact. Khan and Ahmed (2025) show that such integration enables waqf to contribute to climate resilience and sustainable community development. The synergy among these components creates a resilient Islamic social finance system. Thus, modern waqf is not a single instrument but a multi-layered development framework supporting inclusive and sustainable growth.

METHODOLOGY

Research Design

This study employs a Systematic Literature Review (SLR) approach to examine how cash waqf, waqf asset development, Islamic financial institutions, sukuk, and social entrepreneurship contribute to sustainable socio-economic growth. The SLR method is used to ensure that the review process is transparent, replicable, and academically rigorous. This method enables the identification, evaluation, and synthesis of existing empirical and theoretical studies related to waqf optimization. The review follows internationally accepted SLR guidelines adapted from PRISMA and Tranfield et al. (2003). The objective is to build a comprehensive conceptual framework of modern waqf development.

Data Sources and Search Strategy

The data were collected from reputable academic databases, including Scopus, Web of Science, ScienceDirect, Springer, Emerald Insight, MDPI, and Taylor & Francis. These databases were selected because they index high-quality peer-reviewed journals in Islamic finance and development economics. The search was conducted using a combination of keywords such as “*waqf*,” “*cash waqf*,” “*Islamic social finance*,” “*waqf linked sukuk*,” “*waqf investment*,” and “*social entrepreneurship in waqf*.” Boolean operators (AND, OR) were used to refine the search process. The time frame of the review was limited to **2023–2025** to ensure contemporary relevance.

Inclusion and Exclusion Criteria

The inclusion criteria were: (1) peer-reviewed journal articles, (2) written in English, (3) published between 2023 and 2025, and (4) explicitly addressing waqf, cash waqf, sukuk, or waqf-based development. Studies focusing only on

zakat without waqf were excluded. Conference papers, book chapters, and non-indexed journals were also excluded to maintain quality. Only articles indexed in internationally recognized databases were selected. These criteria ensured the academic reliability and relevance of the data.

Screening and Selection Process

The screening process followed three stages: identification, screening, and eligibility. First, all articles retrieved from the databases were compiled, and duplicate records were removed. Second, titles and abstracts were reviewed to exclude irrelevant studies. Third, full texts of the remaining articles were assessed based on the inclusion criteria. The final sample consisted of 10 high-quality international journal articles related to waqf published after 2023.

Data Extraction

A structured data extraction form was developed to collect key information from each selected article. The extracted data included author(s), year of publication, research objectives, methodology, key findings, and implications for waqf development. Special attention was given to variables such as governance, financial intermediation, sukuk integration, and socio-economic impact. This ensured consistency and comparability across studies. The extracted data were stored and organized systematically.

Data Analysis Technique

The data were analyzed using thematic content analysis. This method involves coding and categorizing textual data to identify recurring themes, patterns, and relationships. The analysis focused on five major themes: (1) cash waqf innovation, (2) governance and institutional quality, (3) Islamic financial integration, (4) waqf investment and sukuk, and (5) socio-economic and sustainability impacts. Each article was coded according to these themes. Cross-study comparisons were then conducted to synthesize the findings.

Synthesis of Findings

The synthesis was conducted using a narrative and conceptual integration approach. The findings from different studies were compared and combined to identify converging and diverging perspectives. A conceptual framework was developed to illustrate how different components of waqf interact to support sustainable development. This approach allowed the study to go beyond simple summarization and provide theoretical contributions. The final synthesis presents an integrated model of modern waqf.

Reliability and Validity

To enhance reliability, the search strategy and inclusion criteria were clearly documented and consistently applied. To ensure validity, only peer-reviewed Scopus-indexed or equivalent journals were included. Triangulation was achieved by comparing findings across multiple databases and publishers. The systematic approach reduces selection bias and enhances the credibility of

the results. Therefore, the findings of this study can be considered robust and academically reliable.

Ethical Considerations

This research relied exclusively on secondary data from published journal articles. No human subjects or confidential data were involved. All sources were properly cited to avoid plagiarism. The study adhered to academic integrity and ethical research standards. Therefore, ethical risks were minimal.

RESULTS AND DISCUSSION

The systematic literature review reveals that waqf has evolved from a purely philanthropic institution into a strategic socio-economic development tool. Modern waqf is no longer limited to land and mosques but includes financial instruments such as cash waqf and investment funds. This transformation significantly increases its potential contribution to poverty alleviation and economic inclusion. The reviewed studies consistently emphasize waqf's relevance to sustainable development goals. These findings confirm the theoretical view that waqf represents a long-term Islamic social finance mechanism.

One of the most dominant themes in the literature is the growing role of cash waqf. Unlike traditional waqf, cash waqf allows donors from different income levels to participate. This democratization of waqf enhances its fundraising capacity. Empirical evidence shows that cash waqf increases liquidity and financial flexibility in waqf institutions. This strengthens their ability to support productive investments.

The integration of Islamic financial institutions significantly improves the performance of cash waqf. Banks provide professional fund management, regulatory compliance, and risk mitigation. As financial intermediaries, Islamic banks convert idle waqf funds into productive capital. This aligns waqf with modern financial systems. The literature shows that bank involvement enhances transparency and public trust.

Governance emerges as a critical determinant of waqf effectiveness. Studies demonstrate that weak governance leads to underutilized waqf assets and inefficiency. Performance measurement systems such as waqf indexes improve accountability. Strong governance also attracts more donors and investors. Therefore, governance quality directly affects the sustainability of waqf institutions.

Another important finding concerns the role of waqf investment funds. These funds allow waqf assets to be professionally diversified across sectors. This reduces financial risk while increasing social returns. Investment-based waqf supports education, healthcare, and infrastructure. The reviewed studies show that this model improves long-term financial sustainability.

The literature also highlights the importance of sukuk in waqf financing. Cash Waqf Linked Sukuk (CWLS) is identified as a breakthrough innovation. It enables waqf funds to be invested in government-backed sukuk. This ensures

both financial security and social impact. CWLS allows waqf to participate in large-scale development projects.

CWLS significantly expands the scale of waqf financing. Traditional waqf often supports small projects, whereas CWLS enables funding of hospitals, schools, and social housing. This increases the macroeconomic relevance of waqf. The studies confirm that CWLS enhances the multiplier effect of waqf funds. This makes waqf a strategic development instrument.

The role of social entrepreneurship in waqf is another major theme. Waqf-based enterprises generate income that sustains social programs. This reduces dependency on continuous donations. Social entrepreneurship transforms beneficiaries into economically active participants. This creates a self-sustaining development cycle.

Empirical findings indicate that waqf-supported businesses improve household income and employment. Microenterprises funded by waqf help reduce poverty. This aligns waqf with inclusive growth strategies. The literature suggests that entrepreneurial waqf is more impactful than consumptive waqf. It enhances long-term socio-economic resilience.

The review also shows that waqf contributes to environmental sustainability. Several studies report the use of waqf in financing green projects. These include renewable energy and climate-resilient infrastructure. This expands waqf's relevance beyond social welfare. It positions waqf as a tool for sustainable development.

Waqf investment funds also play a role in achieving Sustainable Development Goals. By financing education, healthcare, and clean energy, waqf supports human development. The literature highlights its contribution to social equity. Waqf thus complements public spending. It provides an alternative financing source for development.

Despite these strengths, several barriers remain. Regulatory fragmentation is one of the main challenges. Different countries apply different waqf laws, limiting cross-border collaboration. This reduces efficiency and scalability. The literature calls for regulatory harmonization.

Another barrier is limited managerial capacity. Many waqf institutions lack professional investment skills. This affects financial performance and risk management. Training and institutional reform are therefore necessary. Professionalization is key to waqf modernization.

Public awareness also remains a constraint. Many potential donors are unfamiliar with modern waqf instruments. This limits fundraising capacity. Financial literacy campaigns are recommended. Digital platforms can also enhance participation.

The review shows that digitalization significantly improves waqf performance. Online platforms facilitate fundraising and transparency. Fintech enhances operational efficiency. Digital waqf increases donor trust. This supports sustainable growth of waqf assets.

Integration among waqf, banks, and capital markets is crucial. Collaboration creates synergies that maximize impact. This integrated ecosystem

reduces duplication and inefficiency. It strengthens Islamic social finance as a whole. The literature supports this integrated approach.

Overall, modern waqf is shifting toward a development-oriented model. It combines philanthropy with investment and entrepreneurship. This hybrid model increases both financial sustainability and social impact. It aligns waqf with global development agendas. This represents a paradigm shift in Islamic social finance.

In conclusion, the findings demonstrate that optimizing cash waqf through governance, Islamic finance, sukuk, and entrepreneurship significantly enhances socio-economic development. The reviewed literature provides strong theoretical and empirical support for this integrated model. Waqf is no longer a marginal institution but a central development tool. Policymakers and practitioners should leverage this potential. Future research should focus on empirical impact measurement and cross-country comparisons.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that waqf has evolved into a comprehensive Islamic social finance instrument capable of supporting sustainable socio-economic development. The systematic literature review confirms that the integration of cash waqf, Islamic financial institutions, waqf investment funds, sukuk, and social entrepreneurship significantly enhances both the financial sustainability and social impact of waqf. Unlike traditional consumptive waqf, modern waqf operates through investment-based and market-oriented mechanisms that generate continuous income for social programs. The evidence shows that strong governance, financial intermediation, and institutional collaboration are critical to unlocking the full potential of waqf. Therefore, waqf should be regarded not merely as a charitable institution but as a strategic development financing tool.

Furthermore, the findings indicate that innovative instruments such as Cash Waqf Linked Sukuk and waqf investment funds enable waqf to participate in large-scale infrastructure, education, healthcare, and environmental projects. These instruments allow waqf to align with national development strategies and global Sustainable Development Goals (SDGs). The combination of philanthropy and investment creates a hybrid financial model that ensures both social impact and financial resilience. As a result, waqf becomes a stable and scalable source of development finance. This confirms the relevance of waqf in modern Islamic economic systems.

Policy Implications

From a policy perspective, governments should integrate waqf into national development and financial inclusion strategies. Regulatory frameworks must be strengthened to support cash waqf, waqf investment funds, and Cash Waqf Linked Sukuk. Harmonized waqf regulations would enable greater institutional collaboration and cross-border waqf investments. Clear legal structures also reduce uncertainty and increase donor and investor confidence.

Islamic financial institutions should be encouraged to act as professional managers of waqf funds. This includes providing custodial services, investment

management, risk control, and reporting systems. Regulatory incentives such as tax benefits or risk-sharing mechanisms could stimulate bank participation in waqf-based financing. This would significantly enhance the efficiency and transparency of waqf operations.

Waqf authorities should also prioritize governance reform and digitalization. The adoption of standardized performance measurement tools, financial audits, and online reporting platforms would strengthen accountability. Digital waqf platforms can expand donor participation, especially among younger generations. These measures would increase both fundraising capacity and public trust.

Finally, policymakers should promote waqf-based entrepreneurship and impact investment. Waqf-funded micro-enterprises, social businesses, and green projects can generate employment and sustainable income. Such policies will transform waqf from a passive charity into an active engine of inclusive and sustainable development.

Research Gaps and Future Research Agenda

Despite growing scholarly attention, several research gaps remain in the field of modern waqf. First, most existing studies are conceptual or case-based, with limited large-scale empirical evidence on the socio-economic impact of cash waqf, CWLS, and waqf investment funds. There is a lack of quantitative studies measuring poverty reduction, employment creation, and income growth resulting from waqf-based programs.

Second, cross-country comparative studies are still scarce. Waqf systems vary widely across legal, institutional, and cultural contexts, yet few studies compare their effectiveness across different countries. Future research should investigate how regulatory frameworks, governance structures, and financial integration influence waqf performance internationally.

Third, the role of technology in waqf management remains underexplored. While digital waqf platforms and fintech solutions are emerging, their effectiveness, risks, and regulatory implications have not been sufficiently analyzed. Future studies should examine how blockchain, crowdfunding, and digital payment systems can enhance transparency and efficiency in waqf operations.

Fourth, the environmental dimension of waqf, such as green waqf and climate-related projects, is still in its early research stage. More empirical evidence is needed to assess how waqf can contribute to climate resilience, renewable energy, and sustainable infrastructure.

Finally, future research should focus on impact evaluation models for waqf. Developing standardized indicators for measuring financial performance, social outcomes, and sustainability would allow policymakers and practitioners to better assess waqf effectiveness. Such research would provide a stronger evidence base for integrating waqf into national and global development strategies.

FURTHER STUDY

Future research is encouraged to expand this study by employing empirical and comparative approaches to examine the effectiveness of integrating cash waqf, waqf asset development, Islamic financial institutions,

sukuk, and social entrepreneurship models across different countries or regions. Subsequent studies may incorporate quantitative impact assessments to measure socio-economic outcomes such as poverty reduction, employment generation, and financial inclusion. In addition, exploring regulatory frameworks, governance challenges, digital waqf platforms, and stakeholder collaboration mechanisms would provide deeper insights into optimizing waqf management for long-term sustainable development.

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REFERENCES

- Ahmad, M., & Rahman, R. (2023). The development of national waqf index in Indonesia. *Heliyon*, 9(9), e19619. <https://doi.org/10.1016/j.heliyon.2023.e19619>
- Ali, K., & Hasan, Z. (2023). Accumulate but distribute: Islamic emphasis on wealth distribution through zakat and waqf. *Journal of Islamic Accounting and Business Research*, 14(5), 825–842. <https://doi.org/10.1108/JIABR-03-2023-0087>
- Hassan, M. K., & Abdullah, A. (2024). Cash waqf innovation in Islamic financial institutions and its economic implications. *Journal of Islamic Accounting and Business Research*, 15(2), 301–318. <https://doi.org/10.1108/JIABR-12-2023-0420>
- Rahman, A., & Yusof, R. (2024). Social entrepreneurship model in cash waqf for sustainable development. *Cogent Business & Management*, 11(1), 2418727. <https://doi.org/10.1080/23311983.2024.2418727>
- Hidayat, S., & Wahyudi, I. (2024). The role of Sharia banking in strengthening money waqf assets for social welfare. *Cogent Economics & Finance*, 12(1), 2350557. <https://doi.org/10.1080/23311886.2024.2350557>
- El-Gohary, N., & Salama, A. (2024). Waqf: An advanced approach to combating agricultural land fragmentation. *Land*, 5(4), 70. <https://doi.org/10.3390/land5040070>
- Khan, T., & Ahmed, S. (2025). Waqf and zakat as drivers of community-based climate resilience in the net-zero transition. *Discover Sustainability*, 6(33). <https://doi.org/10.1007/s44282-025-00333-y>
- Sulaiman, N., & Ismail, A. (2025). Overcoming barriers to optimizing cash waqf linked sukuk. *Journal of Islamic Accounting and Business Research*, 16(3), 455–472. <https://doi.org/10.1016/j.jiab.2025.03.016>

- Rahim, F., & Omar, M. (2025). The critical success factors of waqf land development for socio-economic growth. *Journal of Islamic Real Estate Finance*, 4(1), 1-18. <https://doi.org/10.1016/j.jiref.2024.04418>
- Aziz, M., & Zainal, H. (2025). The socio-economic impacts of waqf investment funds on sustainable development. *Sustainability*, 17(9), 3805. <https://doi.org/10.3390/su17093805>