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SYNCHRONIZING STATE UTILITY AND SOLAR PV GOVERNANCE FOR INDONESIA'S NET-ZERO 2060 TRANSITION: A CO-CREATION AND QUR'ANIC ETHICS FRAMEWORK

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Abstract

Indonesia's transition toward net-zero emissions by 2060 requires more than expanding solar photovoltaic (PV) capacity; it also demands coordination among electricity-system planning, grid infrastructure, regulatory institutions, financing, human-resource development, and energy justice. This study aims to develop an integrated governance framework for synchronizing state utility operations and solar PV development through co-creation and Qur'anic ethics. Using a qualitative library research design and document analysis, the study examines Indonesian energy policies, electricity planning documents, relevant scholarly literature, and Qur'anic interpretations. The analysis identifies six interrelated governance domains: system planning and grid integration, institutional coordination, financing and investment, human-resource and technological capabilities, equitable energy access, and decarbonization with environmental stewardship. These domains are integrated into a conceptual framework that connects co-creation mechanisms, institutional responsibilities, ethical principles, and proposed key performance indicators (KPIs). The Qur'anic ethical layer emphasizes justice, trust, accountability, competence, and environmental responsibility as normative foundations for evaluating governance decisions. The study proposes a KPI roadmap toward 2060 to support monitoring of grid readiness, institutional performance, investment mobilization, workforce development, and transition outcomes. However, the proposed indicators require operational definitions, baseline verification, and stakeholder validation before implementation. This study contributes a governance-oriented framework for aligning Indonesia's solar PV ambitions with institutional coordination, public accountability, and equitable energy-transition outcomes.

Keywords: Solar photovoltaic; energy governance; co-creation; Qur'anic ethics; net-zero emissions

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1. INTRODUCTION

The global energy transition has positioned solar photovoltaic (PV) technology as a key component of decarbonization. However, expanding solar generation requires more than technological improvements and increased installed capacity. It also depends on coordinated network infrastructure, storage, investment, regulation, and institutional capabilities. The International Energy Agency emphasizes that grid modernization, system flexibility, and energy storage are essential for integrating variable renewable energy (International Energy Agency, 2023, 2024b, 2024a). Accordingly, the challenge for emerging economies is to align technical, institutional, financial, and social arrangements to ensure reliable and sustainable deployment. This challenge reflects the broader understanding that sustainability transitions involve technological and institutional transformation (Geels, 2002; Markard et al., 2012) .

Indonesia provides an important context for examining this challenge. PT PLN (Persero) remains central to electricity-system operation and planning, while national strategies establish a pathway toward net-zero emissions by 2060. The National Electricity General Plan (RUKN) 2025–2060 and PLN's Electricity Supply Business Plan (RUPTL) 2025–2034 provide strategic directions for transforming electricity generation and expanding renewable energy (Ministry of Energy & Mineral Resources, 2025a, 2025b) . Nevertheless, the gap between solar deployment ambitions and implementation remains a concern. Addressing it requires examining the conditions that enable planned capacity to be developed, financed, connected, and operated effectively (International Energy Agency, 2022; International Renewable Energy Agency, 2022) .

Several interdependent constraints contribute to this gap. Technically, increasing solar penetration requires adequate grid capacity, forecasting, balancing, storage, and digital monitoring (International Energy Agency, 2023, 2024b, 2024a) . Institutionally, regulatory changes may affect investment predictability, while financing conditions, procurement arrangements, and risk allocation influence private-sector participation. Organizational capabilities and workforce skills are also necessary. Furthermore, affordability, regional access, public participation, and equitable benefit distribution remain important considerations. These challenges are interconnected: investment may not produce effective deployment when grid capacity is insufficient, while technically feasible projects may remain unrealized under uncertain regulatory or financial conditions. Indonesia's solar transition must therefore be understood as a governance and coordination challenge as well as an engineering and investment problem.

Existing scholarship addresses these issues through complementary perspectives. Sustainability-transition research examines changes in technologies, institutions, and organizational practices (Geels, 2011; Markard et al., 2012) . Collaborative-governance studies emphasize structured interaction among public and non-state actors (Ansell & Gash, 2008;

Emerson et al., 2012) , while energy-justice scholarship examines the distribution of transition benefits and burdens (Jenkins et al., 2016, 2018; McCauley & Heffron, 2018) . However, integrating these perspectives raises a central question: how can planning, institutional authority, investment, technology, and social objectives be coordinated while preserving the distinct responsibilities of different actors?

This study addresses that question through synchronization, defined as the coordinated alignment of interdependent system components while preserving their distinct functions. Synchronization serves as an analytical lens rather than a claim that a universally established energy-synchronization theory exists. Co-creation explains how stakeholders jointly generate value, while polycentric governance clarifies how multiple decision-making centers can contribute to shared objectives. These perspectives are complemented by research on collective action, organizational adaptation, ecological limits, and the common good (Daly, 1977; Ostrom, 1990, 2010a, 2010b; Teece, 2007) . Energy justice further provides criteria for evaluating participation and the distribution of transition outcomes.

The framework also incorporates Qur'anic ethics as a normative dimension of energy governance. Principles such as *amānah* (responsibility), *'adl* (justice), *mīzān* (balance), cooperation, and avoidance of waste are interpreted as criteria for evaluating accountability, equitable access, resource efficiency, and environmental responsibility. These principles are informed by Qur'anic interpretation and scholarship on Islamic environmental ethics (Sayem, 2021; Shihab, 2012) . They guide governance evaluation without replacing technical evidence or treating scripture as an engineering specification.

Accordingly, this study asks: (1) What forms of misalignment characterize PLN governance and solar PV development in Indonesia's transition toward net-zero emissions by 2060? (2) How can co-creation and polycentric governance support synchronization across relevant actors and system components? and (3) How can Qur'anic ethical principles be translated into operational criteria and measurable indicators? The study develops a six-domain framework covering energy systems and planning, institutions and governance, investment and finance, human resources and technology, energy justice, and decarbonization and environmental sustainability, with a cross-cutting ethical layer. Its contribution is an integrated framework for assessing Indonesia's solar transition across technical, institutional, financial, social, and ethical dimensions. As the study relies on documentary analysis, further stakeholder-based empirical validation is necessary before the proposed indicators are adopted as a definitive performance-assessment instrument.

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2. LITERATURE REVIEW

2.1. Synchronization and Sustainability Transitions

Synchronization provides the overarching analytical lens for examining the alignment of interconnected components within complex systems. In nonlinear science, synchronization describes coordinated behavior among interacting systems with different dynamics (Pikovsky et al., 2001) . In management, Sawhney (2002) emphasizes the coordination of information, technology, and organizational processes rather than their homogenization. Applied to Indonesia's solar photovoltaic (PV) transition, synchronization refers to the alignment of electricity planning, grid capabilities, institutional responsibilities, investment arrangements, and social objectives while preserving the distinct functions of participating actors.

This perspective complements sustainability-transition research, which conceptualizes energy transformation as a process involving technological innovation, institutional change, and shifts in established practices (Geels, 2002, 2011; Markard et al., 2012) . Solar deployment may remain constrained when infrastructure, regulation, financing, and organizational capabilities develop at different rates. Therefore, synchronization shifts the analytical focus from individual projects toward the relationships among system components. Recent analysis by the International Energy Agency (International Energy Agency, 2024b) similarly emphasizes that successful integration of solar and wind requires coordinated infrastructure development, regulatory reform, system flexibility, and strategic planning. Synchronization is consequently used here as an integrative analytical construct rather than as a claim that a universally established energy-synchronization theory already exists.

2.2. Co-Creation, Collaborative Governance, and Polycentricity

Co-creation theory provides the principal explanation of how multiple actors can generate value through interaction. *Prahalad & Ramaswamy (2000, 2004)* and *Ramaswamy & Ozcan (2014)* emphasize that value creation extends beyond one-way delivery by a dominant organization. In electricity systems, this perspective recognizes the contributions of utilities, regulators, developers, investors, technology providers, communities, and consumers. Co-creation does not require equal authority among stakeholders; rather, it requires structured interaction that enables complementary resources and capabilities to contribute to shared objectives.

Collaborative-governance scholarship strengthens this argument by explaining how public institutions and non-state actors can participate in collective decision-making *(Ansell & Gash, 2008; Emerson et al., 2012)* . *Vargo & Lusch (2008)* further conceptualize value creation as an interactive process among actors. For PLN, these perspectives suggest that system reliability and public-service responsibilities can coexist with broader participation in solar development, financing, innovation, and distributed generation.

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Ostrom's (1990) governing-the-commons perspective demonstrates that collective-action challenges cannot always be resolved through centralized state control or unregulated markets alone. Her work on polycentric governance emphasizes multiple decision-making centers connected through institutional arrangements, information, monitoring, and mutual adjustment (Ostrom, 2010a, 2010b) . Research on polycentric energy governance further examines the conditions under which community-energy initiatives can develop and scale (Petrovics et al., 2022) . Community renewable-energy scholarship also highlights the importance of clarifying ownership, participation, and local benefits *(Bauwens, 2016; Walker & Devine-Wright, 2008)* .

Together, these perspectives distinguish three complementary functions: co-creation explains joint value formation, collaborative governance explains structured stakeholder interaction, and polycentric governance explains the distribution of decision-making authority. Synchronization connects these functions by emphasizing coordination across institutional boundaries. Within the Indonesian context, PLN can therefore be conceptualized as a system integrator that maintains reliability while enabling wider participation in generation, technology, investment, and community-based initiatives.

2.3. Dynamic Capabilities, Ecological Modernization, and Smart Grids

Dynamic-capabilities theory explains how organizations respond to changing environments by identifying opportunities, mobilizing resources, and reconfiguring assets and routines (Teece, 2007; Teece et al., 1997) . For PLN, the transition toward a more solar-intensive electricity system requires more than additional infrastructure. It also involves adapting planning procedures, procurement, workforce competencies, digital systems, and operational practices. Organizational capability is therefore a necessary condition for translating renewable-energy targets into implementation.

Ecological modernization theory emphasizes the potential of technological innovation and institutional reform to support environmental improvement *(Mol et al., 2009; Mol & Spaargaren, 2000)* . Solar PV, storage, digital monitoring, and energy efficiency are consistent with this perspective, but their benefits depend on appropriate governance and investment conditions. Without compatible regulation, adequate financing, and institutional coordination, technological improvements may not produce the intended system-wide transformation.

Smart-grid research specifies the technical mechanisms needed to coordinate variable renewable resources, including communication systems, forecasting, storage, flexibility, demand response, and network reinforcement (International Energy Agency, 2023; Komarnicki et al., 2017) . The International Energy Agency (2024a) also identifies batteries as important to secure

energy transitions and support the expansion of renewable generation. Khalid (2024) discusses smart grids and renewable-energy integration challenges, reinforcing the importance of considering technical coordination alongside institutional arrangements. These perspectives demonstrate that synchronization has both organizational and operational dimensions: institutions must coordinate responsibilities while electricity infrastructure must accommodate changing generation and demand patterns.

2.4. Energy Justice, Ecological Limits, and the Common Good

Technical reliability and investment efficiency are insufficient measures of transition success if benefits and burdens are distributed unfairly. Jenkins et al. (2016) conceptualize energy justice through distributional, procedural, and recognition dimensions, while *McCauley & Heffron (2018)* connect climate, energy, and environmental justice to just transition. Jenkins et al. (2018) further develop an ethical framework for understanding justice in sociotechnical transformation. *Carley & Konisky (2020)* emphasize equity in the transition to clean energy, while *Newell & Mulvaney (2013)* examine the political economy of just transition.

These concerns are particularly relevant when assessing affordability, regional electrification, community participation, and the allocation of transition opportunities. *Taiwo & Tozer (2025)* extend this discussion through community energy justice, highlighting the convergence of community participation, energy transition, and justice. Accordingly, energy justice is incorporated into the synchronization framework as a substantive domain rather than an external social consideration.

Steady-state economics introduces a complementary ecological constraint. Daly (1977) distinguishes qualitative development from indefinite growth in material and energy throughput. This perspective encourages attention to efficiency, environmental limits, lifecycle impacts, and the avoidance of waste. *Daly & Cobb (1989)* extend the argument through the common-good perspective, emphasizing collective welfare, community, and environmental sustainability. Moore (1995) similarly provides a public-value perspective for evaluating government action beyond narrow financial outcomes. These approaches support evaluating energy investment not only through cost and bankability but also through ecological consequences, access, and public benefit. Ecological modernization, steady-state economics, and the common good thus offer complementary perspectives on technological improvement, resource constraints, and the purposes of energy development.

2.5. Qur'anic Ethics as a Cross-Cutting Accountability Layer

Qur'anic ethics provides the normative dimension of the proposed framework. This study applies a restricted thematic-scientific interpretive approach, tafsir ilmi mawdū'ī muqayyad, in

which relevant verses are interpreted through selected exegetical sources before being translated into principles applicable to a defined governance problem (Lajnah Pentashihan Mushaf Al-Quran, 2015; Mustaqim, 2015) . Classical and contemporary tafsir, including the works of Al-Qurtubi (1964) , Al-Tabari (2000) , Ibn Ashur (1984) , and Shihab (2012) , provide interpretive foundations. Sayem (2021) offers additional scholarship on Islamic environmental ethics.

The framework draws on amānah (trust and responsibility), ‘adl (justice), mīzān (balance), ta‘āwun (cooperation), and avoidance of isrāf (wastefulness). These principles inform accountability, fair distribution, institutional cooperation, resource efficiency, and environmental protection. They are not treated as technical variables or substitutes for engineering evidence. Instead, they provide criteria for evaluating whether governance mechanisms and performance outcomes are responsible, equitable, and environmentally sound.

The distinctive contribution of this integration is to position Qur’anic ethics as a cross-cutting accountability layer rather than a separate technical subsystem. The resulting framework combines synchronization, co-creation, polycentric governance, organizational capabilities, smart-grid integration, ecological constraints, energy justice, and public value. These perspectives jointly support a six-domain model covering system planning, institutions, finance, human resources and technology, energy justice, and decarbonization, with ethical accountability applied across all domains.

3. METHODOLOGY

3.1. Research Design and Data Sources

This study employed a qualitative research design based on library research and document analysis to examine the alignment of policies, institutional arrangements, technical planning, and ethical principles in Indonesia’s solar photovoltaic (PV) transition. A qualitative approach was appropriate because the study sought to synthesize documented relationships and develop an integrative governance framework rather than estimate causal effects statistically (Creswell & Creswell, 2018). Document analysis provided a systematic approach to examining documentary evidence in its institutional and policy contexts (Bowen, 2009) .

The primary documentary corpus comprised three groups: (1) the Qur’an and selected classical, modern, and contemporary tafsir works; (2) Indonesian energy laws, regulations, and planning documents, including the National Energy Policy, RUEN, RUKN 2025–2060, RUPTL 2025–2034, and rooftop-solar regulations; and (3) official energy-transition, electricity, and technical documents issued by Indonesian authorities and relevant international organizations,

particularly the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA). Secondary sources included peer-reviewed research on energy governance, co-creation, sustainability transitions, smart grids, energy justice, and environmental ethics.

Documents were selected according to their relevance to the research questions, institutional or scholarly credibility, and contribution to understanding solar development, electricity-system coordination, or ethical accountability. The RUKN and RUPTL were examined as principal planning documents, while rooftop-solar regulations were used to trace changes in the regulatory arrangements affecting participation, investment, and system planning. The analysis did not assume that regulatory change necessarily indicated policy failure; instead, it examined the implications of regulatory arrangements for coordination and implementation.

The Qur'anic corpus was bounded by themes relevant to order, balance, responsibility, leadership, consultation, competence, equitable distribution, environmental protection, and stewardship. Exegetical triangulation drew on selected works by Al-Tabari, Al-Qurtubi, Ibn 'Ashur, and Shihab. The interpretive procedure followed *tafsir ilmi mawdū'ī muqayyad*, a restricted thematic-scientific approach that connects contextual interpretation with a clearly defined contemporary problem (Lajnah Pentashihan Mushaf Al-Quran, 2015; Mustaqim, 2015) .

3.2. Analytical Procedure

The analysis combined deductive and inductive document analysis. Deductive categories were informed by the study's theoretical framework, while inductive coding allowed recurring issues within the documents to inform the interpretation (Elo & Kyngäs, 2008) . The procedure comprised five stages. First, documentary evidence was organized into six analytical domains: system and planning, institutions and governance, investment and finance, human resources and technology, energy justice, and decarbonization and environmental sustainability. Second, recurring synchronization problems were identified within each domain, including grid-flexibility constraints, regulatory uncertainty, financing challenges, capability gaps, unequal access, and fossil-fuel dependence. Third, relevant theoretical perspectives, including co-creation, governing the commons, polycentric governance, dynamic capabilities, ecological modernization, smart-grid and energy-transition theory, steady-state economics, the common-good perspective, and energy justice, were mapped to the identified problems.

Fourth, relevant Qur'anic verses were examined through selected tafsir sources, and their contextually defensible normative meanings were synthesized into governance principles. For example, interpretations emphasizing competence and trustworthiness informed the analysis of workforce capability and integrity, while principles concerning balance and the avoidance of waste informed the assessment of resource efficiency. Thematic analysis supported the identification and organization of recurring patterns across the documentary corpus (Braun & Clarke, 2006) .

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The development and refinement of themes were guided by transparency and consistency in qualitative analysis (Nowell et al., 2017) .

Fifth, each domain was linked to potential key performance indicators (KPIs) using the combined evidence from Qur'anic principles, theoretical constructs, Indonesian planning documents, and technical or policy sources. The proposed milestones for 2030, 2040, 2050, and 2060 were treated as an evaluative roadmap rather than official government targets unless directly supported by an official document. The analysis followed a systematic sequence of data reduction, presentation, and conclusion development (Miles et al., 2014) .

3.3. Trustworthiness and Limitations

Trustworthiness was considered through the qualitative criteria of credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985) . Credibility was supported by comparing regulatory documents, planning sources, technical reports, scholarly literature, and tafsir. Dependability was addressed through a consistent analytical sequence, while confirmability was supported by traceable documentary sources and identifiable exegetical works. These procedures are consistent with recommendations for transparent and trustworthy thematic analysis (Nowell et al., 2017) .

The study is limited by its reliance on documentary evidence and the absence of interviews with PLN managers, regulators, developers, financiers, communities, and consumers. Accordingly, the framework and proposed KPIs require further empirical validation with relevant stakeholders before being applied as a definitive performance-assessment instrument.

4. RESULTS

4.1. The Target–Implementation Gap in Indonesia's Solar Transition

The documentary synthesis identifies a substantial gap between Indonesia's long-term solar deployment ambitions and the current scale of implementation. The manuscript's planning references indicate a potential solar PV capacity trajectory of approximately 109–115 GW by 2060, while installed solar capacity remained below 1 GW in 2024. The RUKN 2025–2060 describes a long-term transformation of the national electricity system, whereas the RUPTL 2025–2034 plans 69.5 GW of additional generation capacity, including 42.6 GW from renewable sources (Ministry of Energy & Mineral Resources, 2025a, 2025b) . These figures indicate that achieving the long-term trajectory requires coordinated changes in infrastructure, regulation, finance, and institutional capability.

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The analysis identifies six interconnected domains of misalignment. Grid constraints may prevent planned solar capacity from being integrated effectively; regulatory changes may affect investment predictability; financing barriers may delay project development; capability gaps may limit technological adoption; unequal access may constrain the distribution of benefits; and continued fossil-fuel dependence may slow decarbonization. These domains are mutually dependent rather than isolated obstacles.

Table 1. Core synchronization gaps identified through documentary synthesis

Domain	**Identified gap**	**Required synchronization response**
System and planning	Low solar penetration relative to long-term ambitions; constraints in grid flexibility, hosting capacity, storage, and digital visibility	Integrate generation planning with network reinforcement, storage, flexibility, and digital-grid development
Institutions and governance	Regulatory changes, centralized decision structures, uncertain procedures, and limited stakeholder participation	Improve regulatory predictability, clarify institutional roles, and strengthen transparent, participatory coordination
Investment and finance	Project bankability challenges, financing risks, and uncertain project economics	Improve power-purchase arrangements, transparent cost assumptions, risk allocation, and access to green finance
Human resources and technology	Skills and certification gaps, dependence on imported technology, and uneven digital capabilities	Strengthen workforce certification, research and development, technology transfer, and technical standards
Energy justice and distribution	Regional access disparities, affordability concerns, and network losses	Integrate universal-access planning, fair distribution, regional reliability, and efficiency measures
Decarbonization and environment	Continued fossil-fuel dependence and the need to accelerate renewable deployment	Coordinate solar expansion with emissions reduction, environmental safeguards, and system-wide transition planning

Source: Authors' synthesis of the documentary corpus and theoretical framework.

4.2. The Six-Domain Synchronization Framework

The analysis produces a framework comprising six operational domains and one cross-cutting ethical layer.

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The six domains represent the principal dimensions through which the PLN–solar PV relationship can be assessed. The ethical layer evaluates the accountability, fairness, and responsibility of decisions across all domains rather than functioning as an additional technical subsystem.

Table 2. Six-domain synchronization framework and proposed performance indicators

Domain	Main analytical focus	Illustrative governance mechanisms	Selected KPIs
1. System and planning	Alignment of generation, network capacity, storage, and long-term plans	Integrated resource and network planning; transparent hosting-capacity information	Solar curtailment; hosting capacity; SAIDI/SAIFI; storage deployment; grid digitalization
2. Institutions and governance	Alignment of authority, rules, accountability, and participation	Digital permitting; transparent procurement; stakeholder consultation; dispute resolution	Permitting time; tender transparency; participation; policy stability; dispute frequency
3. Investment and finance	Bankability, financing access, investment participation, and fair risk allocation	IPP/PPP arrangements; green finance; transparent LCOE and PPA assumptions; independent audit	Private/IPP investment share; financial-close time; bankable projects; LCOE; cost deviations
4. Human resources and technology	Workforce competence, technology adoption, and operational integrity	Professional certification; R&D; technology transfer; technical standards and audits	Certified workforce; technology adoption; technical errors; R&D activity; integrity indicators
5. Energy justice and distribution	Access, affordability, regional equity, and distribution of benefits	Electrification programs; fair tariffs and subsidies; mini-grids; network-loss reduction	Electrification; regional reliability; network losses; affordability; distributional indicators
6. Decarbonization and environmental sustainability	Renewable deployment, emissions reduction, and environmental protection	Fossil-fuel transition; emissions monitoring; lifecycle and environmental safeguards	Solar capacity; renewable share; carbon intensity; absolute emissions; environmental compliance
Cross-cutting ethical layer	Justice, trust, stewardship, proportionality, and accountability	Public dashboards; independent audit; grievance mechanisms; conflict-of-interest controls	Tender transparency; audit closure; public trust; distributional impact; accountability

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Source: Authors' synthesis. The KPIs are proposed evaluation indicators and should not be interpreted as evidence that the corresponding outcomes have already been achieved.

The first domain establishes the technical foundation of synchronization. Solar deployment must be coordinated with network investment, storage, forecasting, and system flexibility. The second domain addresses institutional interfaces, emphasizing that effective implementation depends on consistent rules, transparent procurement, and clear responsibilities across national and regional actors.

The third and fourth domains address the resources needed to implement the transition. Financial arrangements must make projects investable while distributing risks appropriately, and organizational capabilities must develop alongside the technologies being deployed. The fifth domain ensures that expansion is assessed in terms of access, affordability, and regional distribution rather than aggregate generation alone. The sixth domain connects solar development to emissions reduction and environmental safeguards, recognizing that renewable deployment does not eliminate all environmental impacts.

The cross-cutting ethical layer introduces a second level of evaluation. A project may increase installed capacity but remain problematic if procurement is opaque, benefits are concentrated, or affected communities lack meaningful participation. Accordingly, technical and financial performance should be assessed alongside procedural fairness, responsible resource use, and institutional accountability.

4.3. Operationalization of Qur'anic Ethical Principles

The documentary and exegetical synthesis translates selected Qur'anic principles into governance criteria relevant to the six domains. The interpretation does not treat the Qur'an as a source of specific engineering parameters. Instead, the principles provide a normative basis for evaluating how decisions are made, how resources are managed, and how benefits and burdens are distributed.

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Table 3. Translation of Qur'anic principles into governance criteria

Principle	**Normative interpretation in the study**	**Governance application**
Amānah	Trust, responsibility, and stewardship	Accountability, responsible management of public resources, and conflict-of-interest controls
'Adl and qisṭ	Justice and equitable treatment	Fair procurement, access, participation, and distribution of benefits
Mīzān	Balance and proportionality	Balanced planning, appropriate risk allocation, and consideration of environmental limits
Ta'āwun	Cooperation in beneficial action	Structured collaboration among PLN, government, investors, communities, and technology providers
Avoidance of isrāf	Avoidance of waste and inefficient resource use	Network-loss reduction, efficient resource allocation, and monitoring of avoidable losses
Prevention of fasād	Prevention of destructive harm	Environmental safeguards, emissions monitoring, and assessment of adverse social impacts
Competence and integrity	Capability combined with trustworthiness	Workforce certification, reliable measurement, technical standards, and independent audit

Source: Authors' synthesis of the selected Qur'anic and tafsir corpus.

This translation provides a structured connection between normative interpretation and operational governance. The principles inform the choice and interpretation of indicators, but they do not determine numerical engineering targets. Technical benchmarks must remain grounded in electricity-system evidence, official planning documents, and appropriate technical or economic sources.

4.4. Proposed KPI Roadmap Toward 2060

The framework is further operationalized through a progressive KPI roadmap for 2030, 2040, 2050, and 2060. The roadmap combines system-readiness, institutional, financial, workforce, access, and environmental indicators. Some milestones reflect the planning references used in the manuscript, whereas others are proposed benchmarks developed through the study's synthesis.

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Table 4. Selected proposed KPI milestones

KPI	2030	2040	2050	2060
Solar curtailment	<10%	<5%	<3%	<2%
Grid hosting capacity	20%	40%	60%	>70%
Project permitting time	<180 days	<90 days	<60 days	<30 days
Tender transparency	70%	90%	100%	100%
Private/IPP investment share	40%	60%	70%	>75%
Bankable solar projects	70%	85%	90%	>95%
Certified energy workforce	60%	80%	90%	>95%
National electrification	99%	100%	100%	100%
Network losses	<9%	<7%	<6%	<5%
Solar PV capacity	25 GW	70 GW	100 GW	115 GW*
National emissions reduction	−31%	−60%	−85%	Net zero

Source: Proposed roadmap reproduced from the manuscript's underlying dissertation. These figures are proposed monitoring milestones unless explicitly confirmed as official targets. The manuscript cites approximately 109 GW in one RUKN reference and 115 GW in its proposed roadmap; this difference requires reconciliation before submission. The emissions-reduction baseline and the meaning of the hosting-capacity, transparency, and investment-share indicators should also be explicitly defined.

The roadmap is designed as a monitoring architecture rather than a forecast of an inevitable transition pathway. Declining curtailment alongside increasing hosting capacity would indicate improved technical alignment. Shorter permitting times and greater tender transparency would indicate improved institutional coordination, while higher workforce certification and more bankable projects would suggest stronger implementation capacity. These indicators must be interpreted jointly: increases in installed solar capacity alone cannot establish that the transition is reliable, equitable, or environmentally sustainable.

Overall, the results establish a framework in which system planning, governance, finance, capability, energy justice, and environmental performance are evaluated together. The ethical layer provides a common accountability perspective, while the KPI roadmap offers a proposed means of tracking progress across the transition period.

5. Discussion

5.1. From Renewable Energy Targets to System-Level Synchronization

The findings indicate that Indonesia's solar photovoltaic (PV) transition should not be understood merely as a question of increasing installed capacity. Rather, it requires

synchronization among national planning, electricity-network readiness, institutional coordination, investment mechanisms, human-resource development, and the distribution of social and environmental benefits. This interpretation is consistent with the multi-level perspective on socio-technical transitions, which explains that energy transitions involve interactions among technologies, institutions, established infrastructures, markets, and broader societal expectations (Geels, 2002, 2011; Markard et al., 2012) . Consequently, ambitious capacity targets do not automatically produce an effective transition when the institutional and technical systems responsible for implementation develop at different speeds.

Indonesia's long-term electricity planning provides an important strategic foundation. The RUPTL 2025–2034 identifies 69.5 GW of additional generating capacity, with renewable energy representing a substantial component of planned expansion (Ministry of Energy & Mineral Resources, 2025b) . However, translating these commitments into a sustained solar transition requires alignment between generation procurement and investments in transmission, distribution, storage, forecasting, and system flexibility. The International Energy Agency (International Energy Agency, 2023, 2024b) emphasizes that variable renewable energy integration increasingly depends on changes in system operation, infrastructure, planning, and market arrangements rather than generation investment alone. Khalid (2024) similarly identifies grid flexibility, digitalization, storage, interoperability, and regulatory adaptation as important conditions for integrating renewable electricity into increasingly complex power systems.

These findings extend the discussion of Indonesia's energy transition by framing synchronization as a governance problem as well as an engineering challenge. The six domains identified in the Results section are interdependent: limited grid hosting capacity can delay projects, regulatory uncertainty can increase financing costs, and inadequate technical capabilities can weaken implementation even when policy commitments are clear. A failure in one domain may therefore constrain progress in the others. This systemic interpretation is consistent with the argument that sustainability transitions depend on coordinated institutional and technological change (Geels, 2011; Markard et al., 2012) .

5.2. Grid Integration and the Transformation of Utility Governance

The first domain concerns the relationship between centralized electricity-system management and the growing importance of distributed solar generation. A state utility remains central to maintaining system reliability, coordinating dispatch, planning network investments, and ensuring electricity supply. Nevertheless, increasing solar deployment introduces operational requirements that cannot be addressed solely through conventional centralized generation planning. Forecasting, flexible dispatch, storage, demand response, digital monitoring, and transparent grid-connection procedures become increasingly important as variable renewable generation expands (International Energy Agency, 2023, 2024b; Khalid, 2024) .

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The implication is not that centralized utility coordination should be abandoned. Instead, it should evolve toward a more adaptive system in which the utility coordinates multiple actors and technical resources while maintaining reliability and accountability. Distributed generation creates opportunities for households, commercial users, industrial consumers, and independent power producers to participate in electricity provision. Yet these opportunities depend on the utility's ability to integrate distributed resources without compromising network stability, service quality, or equitable access.

This finding is consistent with Ostrom's (1990, 2010a, 2010b) work on institutional diversity and polycentric governance. Complex collective problems are not necessarily resolved through a single institutional mechanism; effective arrangements may require coordination across multiple decision-making centers, clearly assigned responsibilities, and mechanisms for monitoring performance. Applied to solar PV governance, this perspective suggests that the utility, energy regulators, ministries, local governments, investors, and electricity consumers need defined but complementary roles. Central coordination remains necessary, while participation and information exchange should be strengthened at the operational and local levels.

The technical implications are also substantial. The International Energy Agency (2024b) notes that integrating solar and wind requires timely measures such as grid enhancement, improved forecasting, flexible generation, and demand response. Indonesia's governance framework should therefore connect procurement decisions with evidence of network readiness. The proposed indicators for curtailment, grid hosting capacity, and energy-system transparency can help make this connection visible. However, these indicators should be treated as proposed monitoring benchmarks rather than established official targets until their baselines, calculation methods, and responsible reporting institutions are formally specified.

5.3. Regulatory Coordination, Co-Creation, and Institutional Capabilities

The second and third domains highlight regulatory coordination and organizational capabilities. The evolution of Indonesia's rooftop solar regulations illustrates why policy continuity and implementation clarity matter. Changes to regulatory arrangements can affect the expected value of electricity exports, project economics, and investment decisions. When policy requirements are difficult to anticipate or interpret, project developers and consumers may face greater uncertainty, even when the overall policy direction supports renewable energy. This is particularly relevant to investments whose financial viability depends on long-term operating conditions and predictable administrative processes.

Collaborative governance provides a useful explanation for addressing these challenges. Ansell & Gash (2008) describe collaborative governance as a process through which public institutions and non-state stakeholders engage in structured decision-making. Emerson et al.

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(2012) further emphasize the importance of principled engagement, shared motivation, and capacity for joint action. These perspectives suggest that coordination should extend beyond formal consultation. It should include predictable procedures for resolving implementation problems, transparent communication of regulatory changes, and regular engagement among the utility, regulators, investors, technology providers, and electricity users.

The co-creation perspective adds a complementary dimension. Prahalad & Ramaswamy (2000, 2004) argue that value can emerge through interactions between organizations and stakeholders, while Ramaswamy & Ozcan (2014) emphasize the role of stakeholder participation in shaping value-creation processes. In the solar transition, co-creation may involve joint planning for grid connections, structured feedback on permitting procedures, and the development of practical solutions for rooftop PV, storage, and local electricity demand. It should not, however, be equated with the transfer of public responsibility to private actors. Public institutions retain responsibility for setting rules, protecting consumers, and ensuring that participation does not privilege stakeholders with greater financial or technical resources.

The findings also connect governance reform with organizational capabilities. Dynamic capabilities theory explains how organizations adapt by sensing changes, mobilizing resources, and transforming existing routines (Teece, 2007; Teece et al., 1997) . For a state utility, these capabilities may include integrating renewable forecasts into planning, developing digital grid-management systems, adapting procurement practices, and coordinating new contractual arrangements. The proposed indicators for permitting duration, tender transparency, and project bankability can help assess institutional performance, but they require operational definitions and consistent data collection. These measures are meaningful only when they reflect verifiable administrative outcomes rather than general statements of policy commitment.

5.4. Financing, Human Resources, and the Conditions for Implementation

The fourth and fifth implementation challenges concern financing and human resources. Solar PV deployment requires more than the availability of technology: projects must also secure financing, satisfy technical standards, connect to the electricity network, and operate reliably over time. Financing conditions are influenced by regulatory predictability, perceived project risk, procurement arrangements, and the availability of credible information. International Renewable Energy Agency & Climate Policy Initiative (2023) highlight the importance of mobilizing renewable-energy finance, while International Renewable Energy Agency, 2022, 2023) and the World Bank Group (2023) place energy-transition investment within the broader challenge of transforming Indonesia's energy system.

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From this perspective, bankability should not be treated as an isolated financial outcome. It is partly produced by the interaction between institutional credibility, project preparation, technical feasibility, and revenue expectations. Transparent tenders, clear connection procedures, standardized technical requirements, and credible long-term planning may reduce avoidable uncertainty. Nevertheless, the proposed roadmap's indicators for private investment and bankable projects should be interpreted carefully: a higher private-investment share is not automatically evidence of better public value, and bankability does not by itself demonstrate affordability, equitable access, or environmental integrity.

Human-resource development is equally important. Grid modernization and renewable-energy deployment require expertise in system planning, power electronics, digital monitoring, cybersecurity, project finance, installation, and maintenance. The transition therefore involves changes in organizational learning and professional capability, not merely the procurement of new equipment. Jenkins et al. (2016, 2018) show that energy-system decisions have implications extending beyond technical efficiency, including the distribution of benefits, burdens, and participation. In this context, workforce indicators should account for the relevance and quality of certification, the distribution of training opportunities, and the ability of domestic institutions and firms to sustain operational capabilities.

These findings also support a broader understanding of technological development. Digitalization can improve visibility and coordination, but its effectiveness depends on interoperability, data quality, institutional responsibility, and adequate technical expertise. Khalid (2024) emphasizes the importance of communication systems, grid flexibility, storage, and interoperability in smart-grid development. Accordingly, technology acquisition should be accompanied by institutional learning and clearly assigned responsibility for operation, maintenance, and data governance. Otherwise, technological investments may fail to deliver their expected operational benefits.

5.5. Energy Justice, Participation, and the Distribution of Benefits

The sixth domain concerns the distribution of energy-transition benefits and burdens. A transition can increase renewable generation while leaving important questions unresolved: who can afford to install rooftop solar, which communities receive improved infrastructure, who bears network-development costs, and whether workers and local enterprises can participate in emerging economic opportunities. These questions demonstrate why installed capacity alone is insufficient as a measure of transition performance.

The energy-justice framework developed by McCauley & Heffron (2018) directs attention to distributive, procedural, and recognition dimensions of justice. Carley & Konisky (2020) similarly emphasize that transitions away from fossil fuels can generate unequal social

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consequences if distributional effects are not explicitly addressed. Walker & Devine-Wright (2008) further distinguish projects by considering both the distribution of outcomes and the extent to which communities participate in decision-making. These perspectives imply that solar governance should assess not only the volume of new capacity but also the accessibility of participation and the fairness of resulting benefits.

For Indonesia, this requires attention to differences in household purchasing power, geographic conditions, network readiness, and access to financing. A rooftop solar policy may create opportunities for consumers who can afford the initial investment while offering fewer direct benefits to households that rent their homes or cannot finance installation. Similarly, utility-scale projects may contribute to national capacity expansion without automatically generating equitable local benefits. The policy response should therefore combine technical deployment targets with transparent assessment of affordability, access, community participation, and local economic opportunities.

The proposed indicators for electrification and network losses are useful but incomplete proxies for justice. National electrification coverage does not necessarily reveal differences in affordability, reliability, or service quality. Likewise, average network losses may obscure geographic disparities. A more comprehensive monitoring framework should therefore complement these indicators with measures of electricity affordability, service reliability, access to participation mechanisms, and the distribution of project-related benefits. Such additions would strengthen the connection between system performance and public value, consistent with energy-justice scholarship (Carley & Konisky, 2020; Jenkins et al., 2016, 2018; McCauley & Heffron, 2018) .

5.6. Ecological Limits and the Qur'anic Ethical Layer

The framework's distinctive contribution is its integration of Qur'anic ethical principles into a governance model for the solar transition. The environmental-economics perspective challenges the assumption that economic and technological expansion can be evaluated independently of ecological limits (Daly, 1977; Daly & Cobb, 1989) . Similarly, Newell & Mulvaney (2013) demonstrate that low-carbon transitions raise questions of justice, political power, and the distribution of costs, rather than representing purely technical substitutions between energy technologies. Solar PV can contribute to decarbonization, but its broader environmental performance also depends on land use, material extraction, manufacturing, installation, and end-of-life management.

The Qur'anic ethical layer provides a normative basis for examining these trade-offs. The principles of justice (*al-'adl*), trust and responsibility (*al-amānah*), stewardship, balance, and accountability can be used to assess whether decisions are transparent, fair, ecologically

responsible, and oriented toward public welfare. Interpretations of Qur'anic passages should be grounded in recognized exegetical traditions rather than reduced to isolated slogans (Al-Qurtubi, 1964; Al-Tabari, 2000; Ibn Ashur, 1984; Lajnah Pentashihan Mushaf Al-Quran, 2015; Shihab, 2012) . Mustaqim (2015) also provides a methodological basis for thematic interpretation, which is relevant when connecting scriptural concepts to contemporary public-policy questions.

Within the proposed framework, the Qur'anic principles associated with justice can inform fair procurement and benefit distribution; trust and accountability can guide disclosure and monitoring; stewardship can inform lifecycle assessment and environmental safeguards; and knowledge and competence can support responsible technology development. These associations are interpretive and normative propositions. They do not establish that particular Qur'anic verses prescribe specific engineering standards or numerical performance targets. Instead, they provide ethical criteria through which institutions can evaluate the legitimacy and consequences of their decisions.

The framework's ethical layer becomes practically meaningful when translated into transparent procedures and measurable responsibilities. For example, justice can be operationalized through public reporting on access and benefit distribution; trust through auditable procurement and disclosure; stewardship through lifecycle and environmental assessments; and accountability through monitoring, grievance procedures, and corrective action. This translation is consistent with the broader co-creation perspective, which emphasizes that value emerges through stakeholder interaction (Prahalad & Ramaswamy, 2004; Ramaswamy & Ozcan, 2014) , and with collaborative governance, which emphasizes shared engagement and capacity for collective action (Ansell & Gash, 2008; Emerson et al., 2012) .

Nevertheless, the ethical layer should not be presented as a substitute for technical evidence, legal compliance, or inclusive policy deliberation. Its role is to clarify the normative standards by which decisions are assessed. The relationship between Qur'anic ethics and measurable governance indicators therefore represents a conceptual contribution that requires further validation through stakeholder engagement, expert review, and practical application.

5.7. Policy Sequencing, Measurement, and the Contribution of the Framework

The proposed KPI roadmap translates the six-domain model into a potential monitoring structure extending toward 2060. Its principal contribution is to connect broad transition ambitions with observable indicators of grid performance, institutional processes, investment conditions, workforce readiness, and social outcomes. However, the roadmap should be understood as a proposed analytical instrument, not as a set of officially adopted Indonesian government targets. In particular, the proposed solar PV trajectory of 115 GW must be reconciled with the approximately 109 GW figure identified in the relevant planning reference before either figure is presented as the authoritative national target.

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The roadmap also requires a clear measurement protocol. Each KPI should specify its baseline year, operational definition, unit of measurement, data source, reporting frequency, and responsible institution. For example, grid hosting capacity requires an agreed technical definition; curtailment should specify whether it is measured as a share of available renewable generation or another denominator; permitting duration should define the start and end points of the administrative process; and tender transparency should be measured against explicit disclosure criteria. Without such definitions, numerical targets may create an appearance of precision without supporting meaningful comparison over time.

Policy sequencing is equally important. In the near term, the priority should be to establish consistent definitions, improve data availability, clarify institutional responsibilities, and identify immediate barriers to project connection and implementation. Subsequent stages can expand grid flexibility, digital monitoring, storage, workforce development, and investment mechanisms as system needs evolve. Longer-term evaluation should assess whether these changes contribute to decarbonization, reliable electricity provision, and equitable distribution of benefits. This staged approach is consistent with the International Energy Agency (2024b) emphasis on implementing integration measures in line with the changing requirements of power systems.

The framework also has limitations. Because the study relies on documentary analysis and conceptual synthesis, it does not empirically establish causal relationships between the proposed governance mechanisms and solar deployment outcomes. Nor does it demonstrate that the proposed KPI values are achievable under particular financing, technology, or institutional scenarios. Future research should validate the framework through interviews with utility representatives, regulators, developers, local governments, and electricity consumers; comparative analysis of relevant jurisdictions; and empirical assessment of KPI feasibility. Participatory validation is particularly important for determining how the Qur'anic ethical principles can be interpreted consistently across different institutional settings without excluding stakeholders who do not share the same religious framework.

Overall, the findings support the argument that Indonesia's solar transition requires coordinated changes in technology, institutions, finance, organizational capabilities, and social accountability. The six-domain synchronization model explains how these elements interact, while the Qur'anic ethical layer provides a normative perspective for evaluating fairness, stewardship, and responsibility. By linking system-level coordination with measurable governance indicators, the framework offers a basis for future empirical research and policy evaluation. Its value lies not in claiming that ethical principles automatically produce implementation success, but in proposing a structured way to connect national energy ambitions with institutional action, public accountability, and long-term ecological responsibility.

6. CONCLUSION

This study developed a six-domain synchronization framework for strengthening Indonesia's solar photovoltaic (PV) governance toward the net-zero emissions target by 2060. The findings indicate that achieving this ambition requires more than expanding installed solar capacity; it depends on the alignment of electricity-system planning, grid integration, institutional coordination, financing, human-resource development, and energy justice. The proposed framework integrates these domains with a Qur'anic ethical layer emphasizing justice, trust, accountability, knowledge, and environmental stewardship. By translating these principles into governance practices and proposed key performance indicators (KPIs), the framework provides a conceptual basis for connecting national energy-transition objectives with institutional implementation, transparent monitoring, and equitable distribution of benefits.

This study contributes a governance-oriented perspective that combines socio-technical transition theory, collaborative governance, co-creation, and Qur'anic ethical interpretation. However, because the research relies on documentary analysis and conceptual synthesis, the proposed framework and KPI roadmap require empirical validation before practical adoption. Future research should engage electricity utilities, regulators, project developers, local governments, and energy consumers to assess the feasibility of the proposed indicators, clarify institutional responsibilities, and examine how ethical principles can inform measurable governance outcomes. Ultimately, synchronizing technical capabilities, institutional arrangements, investment mechanisms, and ethical accountability may help Indonesia pursue a solar transition that is not only technologically feasible but also socially equitable and environmentally responsible.

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