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Artificial Intelligence for Energy Transition Governance: A Critical Review of Conceptual Models, Policy Frameworks, and Research Gaps

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Abstract

Governing the energy transition requires managing unprecedented complexity, uncertainty, and scale. Artificial intelligence is increasingly proposed as a means to enhance governance capabilities across policy design, system operation, and stakeholder coordination. Despite growing interest, the literature on AI for energy transition governance is fragmented, lacking systematic syntheses of the conceptual models and policy frameworks that underpin this field. The resulting research landscape is poorly mapped. This review critically examines and synthesises the existing literature on AI for energy transition governance, focusing on conceptual models, policy frameworks, and research gaps. It evaluates how AI is framed as a technical, institutional, and socio-political governance resource. A targeted review of 29 peer-reviewed articles published between 2017 and 2024 is conducted, drawing on transition studies, energy policy, AI governance, and socio-technical literature. The synthesis is organised thematically. The review reveals a predominance of techno-centric conceptual models that underplay institutional and political dynamics. Policy frameworks are mostly generic AI ethics instruments with limited energy-sector specificity. Significant gaps exist in empirical research, justice considerations, and adaptive governance mechanisms. The field urgently needs more integrated, interdisciplinary research that treats AI as a socio-technical governance challenge. The review provides a structured research agenda to guide future work.

Keywords Artificial intelligence, Governance, Energy transition, Conceptual models, Policy frameworks, Research gaps

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Introduction

Governing the energy transition has become a central challenge for contemporary policy because decarbonisation requires simultaneous changes in infrastructure, markets, institutions, and social practices. Markard characterises the next phase of the energy transition as more politically and institutionally demanding than earlier technology deployment phases, because system integration, legitimacy, and coordination become increasingly important [1]. At the same time, artificial intelligence is increasingly represented as a governance-enabling technology capable of supporting prediction, optimisation, coordination, and policy learning in complex energy systems [2]. The literature therefore reveals a dual narrative in which energy transitions generate governance complexity while AI is increasingly promoted as a means of managing that complexity.

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The field remains fragmented because AI for energy transition governance is discussed across energy economics, digitalisation studies, responsible AI, sustainability transitions, and energy justice without a unified conceptual vocabulary. Energy-focused AI studies often examine optimisation, forecasting, or system efficiency, as illustrated by work on renewable energy forecasting and energy-system applications of machine learning [3, 4]. By contrast, AI governance scholarship has developed broader ethical and regulatory principles that are not usually tailored to the infrastructural, public-service, and political characteristics of energy transitions [5, 6]. This separation means that conceptual models of AI-enabled energy transition often advance faster than the policy frameworks needed to govern them.

A critical review is necessary because energy transition governance cannot be reduced either to technical optimisation or to generic AI ethics. Köhler and colleagues argue that sustainability transitions research must address politics, institutions, agency, and directionality rather than treating transitions as linear processes of technological diffusion [7]. Similarly, energy justice scholarship shows that transition governance must account for distributional, procedural, and recognition concerns, especially when new technologies reshape access, risk, and authority [8, 9]. Reviewing conceptual models and policy frameworks together is therefore essential for evaluating whether AI supports democratic and just transition governance or merely accelerates existing technocratic tendencies.

This review examines 29 peer-reviewed articles published between 2017 and 2024 in order to synthesise how AI is conceptualised and governed in relation to energy transitions. It focuses on three linked questions: how the literature models AI's role in transition governance, how policy and governance frameworks address AI in energy contexts, and what research gaps remain unresolved. The review draws on studies of AI and energy transition outcomes [10, 11], digitalisation and energy governance [12, 13], sustainability transitions [7, 14], and AI ethics and governance [5, 6, 15, 16]. The structure proceeds from background and conceptual models to policy frameworks, cross-cutting tensions, research gaps, and a future research agenda.

Figure 1 provides a synthesis map of the review's analytical architecture, showing how AI-enabled energy transition governance is examined through conceptual models, policy frameworks, cross-cutting tensions, and research gaps.

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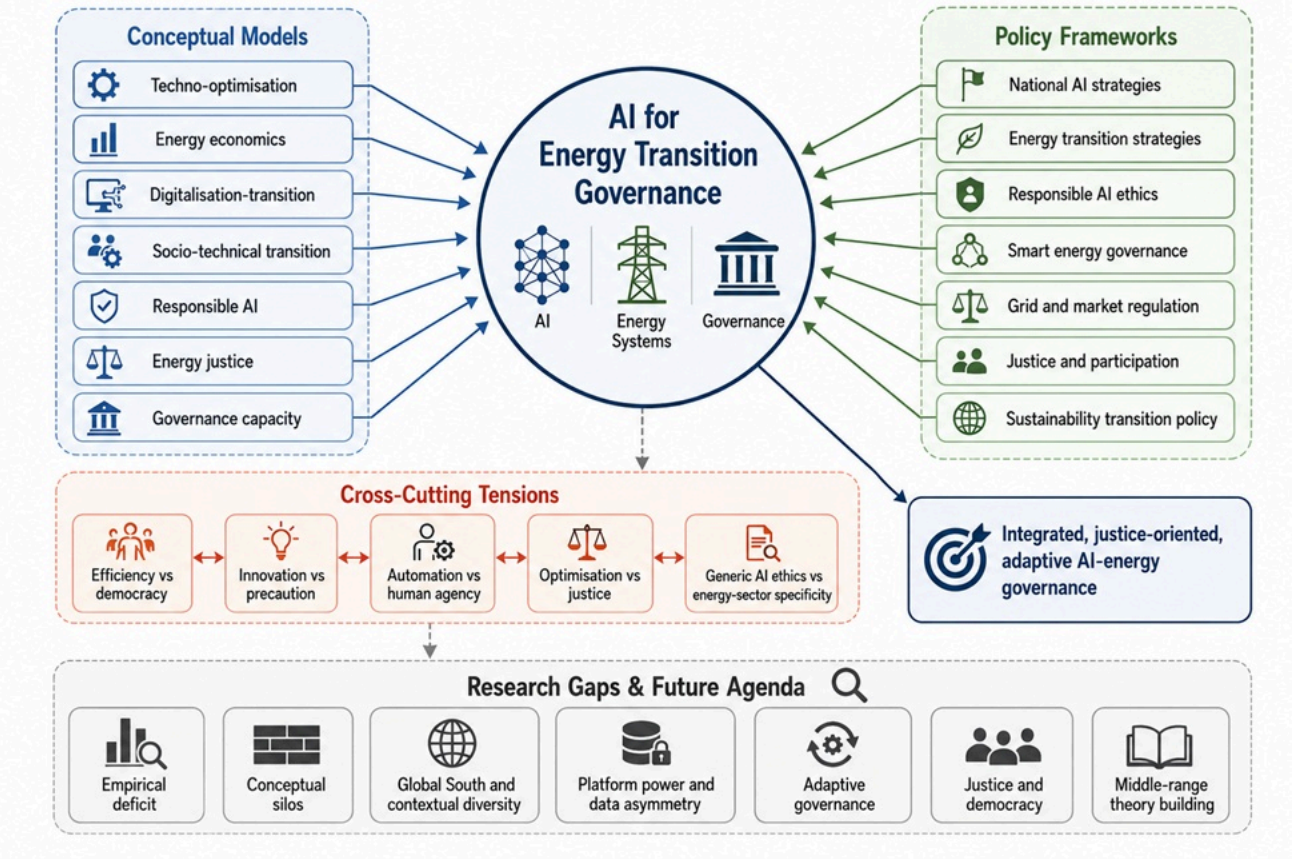

Figure 1. Review synthesis map of AI for energy transition governance: conceptual models, policy frameworks, tensions, and research gaps

Background and Scope

Energy transition governance as a wicked problem

Energy transition governance can be understood as the coordination of technological, institutional, economic, and social change toward low-carbon energy systems under conditions of uncertainty and contestation. The literature on sustainability transitions emphasises that such change is not a simple substitution of clean technologies for fossil technologies, but a reconfiguration of socio-technical systems involving actors, rules, infrastructures, markets, and cultural meanings [7]. Markard's account of the next phase of energy transition highlights how governance problems intensify as renewable integration, electrification, decentralisation, and sector coupling require new forms of coordination [1]. This makes energy transition governance a wicked problem because policy-makers must balance speed, reliability, affordability, legitimacy, and justice without full knowledge of future system dynamics.

The rise of AI in energy systems and governance

AI has entered energy systems through forecasting, smart energy management, demand response, building optimisation, energy finance, and renewable energy integration. Reviews of AI and machine learning in energy systems show that technical applications have expanded across generation, consumption, storage, and markets, with AI frequently framed as a tool for improving efficiency, prediction, and operational responsiveness [17, 18]. More recent studies connect AI to macro-level energy transition outcomes, asking whether AI can promote cleaner energy systems, reduce emissions, or support low-carbon transitions [2, 10]. The governance relevance of this shift lies in the fact that AI-enabled operational

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tools increasingly influence policy-relevant decisions about resource allocation, system reliability, market behaviour, and infrastructure planning.

Conceptualising AI's role: from tool to actor

The reviewed literature conceptualises AI in at least three ways: as a decision-support tool, as an autonomous optimisation actor, and as part of a wider governance infrastructure. Technical energy studies often treat AI as an instrument for forecasting, optimisation, and system control, especially in renewable energy and smart energy management contexts [3, 4]. Digitalisation scholarship broadens this view by showing that data infrastructures, platforms, and information systems can reshape energy-sector organisation and governance, not merely improve technical performance [12, 19]. From a governance perspective, this implies that AI should not be treated as a neutral tool, because its deployment can redistribute authority, structure participation, and affect whose interests are encoded into transition decisions.

Policy frameworks for AI governance: general and sector-specific

AI governance frameworks have largely emerged from general debates about fairness, accountability, transparency, privacy, and human oversight rather than from energy-sector-specific regulatory traditions. Jobin, Ienca, and Vayena show that global AI ethics guidelines converge around broad principles, yet differ in implementation mechanisms and institutional enforceability [5]. Mittelstadt argues that principles alone cannot guarantee ethical AI because they often lack professional accountability structures, practical translation, and mechanisms for resolving conflicts among values [6]. For energy transition governance, this creates a policy gap because energy systems require sector-specific attention to reliability, public obligations, market integrity, infrastructure security, and long-term decarbonisation.

Prior reviews and the gap this review fills

The review was designed as a targeted critical review rather than a systematic review or quantitative meta-analysis. Existing reviews on AI in energy systems, renewable energy forecasting, machine learning in energy economics, smart energy management, and digitalisation provide important technical and sectoral foundations, but they do not sufficiently integrate conceptual models, policy frameworks, and governance gaps into a single critical synthesis [4, 12, 17, 18, 20]. Studies were selected when they were peer-reviewed journal articles published between 2017 and 2024 and contributed directly to at least one of three domains: AI applications relevant to energy transition governance, policy or governance frameworks for AI and digitalisation, or socio-technical, justice-oriented, and ethical debates relevant to governing AI-enabled transitions [5, 7, 8]. Articles were excluded when they focused only on technical model performance without governance relevance, fell outside the time window, or were not peer-reviewed journal articles. The final set of 29 studies was purposively selected to balance AI-energy applications, digitalisation, transition studies, responsible AI, energy justice, and policy-oriented governance scholarship.

Review of Conceptual Models

Techno-centric models: AI as optimisation engine

Techno-centric models dominate much of the AI-energy literature by treating AI as an optimisation engine for forecasting, energy management, system efficiency, and emissions reduction. Studies on deep learning for renewable energy forecasting and AI applications in renewable energy systems show the analytical power of predictive models, yet their governance assumptions often remain implicit [3, 4]. Energy economics research similarly investigates whether AI promotes energy transition or cleaner energy outcomes, but such work often frames governance as an enabling condition rather than as a contested process of institutional design [2, 21]. The limitation of this model is that it can obscure questions of accountability, legitimacy, and political choice by presenting transition governance as a problem of better prediction and more efficient optimisation.

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Socio-technical and transition models: AI in system change

Socio-technical and transition-oriented models offer a broader view by situating AI within digitalisation, institutional change, innovation systems, and sustainability transitions. Sareen and Haarstad argue that digitalisation can drive transformative environmental innovation, but they also imply that such transformation depends on governance arrangements rather than technology alone [14]. Fouquet and Hippe place decarbonisation and digitalisation in historical perspective, showing that information systems and energy systems have co-evolved across long periods rather than developing as separate domains [13]. These models are valuable because they recognise AI as part of broader transition dynamics, yet they often remain underdeveloped in specifying how AI governance should be institutionally organised.

Governance-centric models: AI for policy and regulation

Governance-centric models focus more directly on how AI may affect policy learning, regulatory oversight, institutional capacity, and public accountability in energy transitions. Dong and colleagues highlight regulatory quality as a guardrail in the relationship between AI and energy transition, suggesting that governance conditions mediate whether AI supports or undermines transition outcomes [11]. Research on the digital economy and energy transition similarly shows that institutional and economic contexts shape the relationship between AI, digitalisation, and low-carbon change [22, 23]. As shown in **Table 1,** the strongest governance-centric models move beyond AI as a technical instrument, yet they still require more explicit engagement with democratic control, legal accountability, and sector-specific energy regulation.

Table 1. Comparative Analysis of Conceptual Models for AI in Energy Transition Governance

Model Type	Core Logic	AI's Role in Governance	Key Dimensions Addressed	Limitation
Techno-optimisation model	Energy transition problems are framed as prediction, allocation, and efficiency challenges.	AI supports forecasting, optimisation, control, and system balancing.	Operational efficiency, renewable integration, demand management, emissions reduction.	Under-specifies accountability, institutional authority, political conflict, and public legitimacy.
Energy economics model	AI affects energy transition through productivity, innovation, trade, regulation, and macroeconomic channels.	AI becomes an economic driver that may accelerate or condition transition pathways.	Energy intensity, carbon emissions, digital economy, regulatory quality, trade openness.	Often treats governance variables as external moderators rather than sites of contestation.
Digitalisation-transition model	AI is part of wider digital transformation in energy systems and business models.	AI enables data-driven coordination, platformisation, and new organisational forms.	Digital infrastructures, business models, energy demand, institutional change.	Risks conflating digital capability with governance capacity.
Socio-technical transition model	AI is embedded in multi-actor, multi-level transition processes.	AI shapes and is shaped by regimes, niches, institutions, and user practices.	Directionality, system change, innovation dynamics, transition politics.	Provides rich conceptual framing but limited operational guidance for AI-specific governance.
Responsible AI model	AI deployment should follow ethical principles such as transparency,	AI is governed through normative principles, safeguards, and	Ethics, trust, human agency, transparency, fairness.	Often generic and insufficiently adapted to energy-sector

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	fairness, accountability, and human oversight.	accountability mechanisms.		reliability and justice obligations.
Energy justice model	Transition technologies must be assessed through distributional, procedural, and recognition justice.	AI is a governance object that may reproduce or reduce transition inequalities.	Equity, participation, recognition, public accountability.	Still rarely integrated into technical AI-energy studies or formal policy instruments.
Governance-capacity model	AI's contribution depends on institutional ability to regulate, monitor, and adapt.	AI supports policy learning and surveillance but also creates new oversight burdens.	Regulatory quality, institutional capacity, adaptive governance, market oversight.	Needs stronger empirical grounding and clearer mechanisms for democratic accountability.

Review of Policy Frameworks

National AI strategies and energy policy integration

The literature suggests that national AI strategies often frame AI as an innovation and competitiveness agenda, while energy policy integration remains uneven and frequently indirect. Studies linking AI, digital economy development, and energy transition indicate that national governance quality and digital infrastructure can shape whether AI contributes to low-carbon outcomes [11, 22]. However, these accounts also reveal that AI policy and energy transition policy are often treated as parallel domains rather than as integrated governance challenges. A recurring gap is that national strategies may promote AI adoption in energy systems without specifying how energy regulators, utilities, market operators, and affected communities should govern AI-enabled decision-making.

International and regional governance initiatives

International and regional AI governance initiatives have advanced broad principles for trustworthy AI, but the literature indicates that their application to energy transition remains limited. Floridi and Cowls propose a unified framework of principles for AI in society, including beneficence, non-maleficence, autonomy, justice, and explicability, which are relevant to energy governance but not energy-specific [16]. Cath similarly identifies ethical, legal, and technical opportunities and challenges in governing AI, yet the framework remains broad rather than tailored to energy-system infrastructures and transition politics [15]. For energy transitions, the weakness of these initiatives is not their normative ambition but their limited translation into sector-specific rules for grid reliability, energy markets, consumer participation, and transition justice.

Sector-specific regulatory instruments

Sector-specific regulation in energy has begun to encounter AI through market monitoring, grid management, flexibility services, smart buildings, and digital platforms, but the reviewed literature shows that explicit AI governance provisions remain underdeveloped. Digitalisation research demonstrates that energy platforms and digital business models can reshape value creation, consumer roles, and market coordination, which implies a need for regulatory attention beyond conventional grid codes or market rules [19, 24]. Research on digitalisation and energy consumption also warns that digital technologies may increase energy demand, meaning that AI governance must address rebound effects as well as optimisation benefits [25]. **Table 2** therefore categorises policy frameworks by governance level, instrument type, energy transition relevance, AI specificity, and remaining governance gaps.

Table 2. Overview of Policy Frameworks for AI in Energy Transition Governance

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Framework/Initiative	Level	Core Policy Instruments	Energy Transition Relevance	AI Specificity	Identified Governance Gap
National AI innovation strategies	National	Industrial policy, research funding, digital infrastructure investment, skills programmes.	Supports AI capacity that may be applied to energy planning, grids, markets, and demand management.	Medium; AI is explicit but energy applications are often secondary.	Weak integration with energy regulators, utilities, and transition justice objectives.
National energy transition strategies with digital components	National	Decarbonisation targets, grid modernisation plans, smart-meter programmes, renewable integration policies.	Directly linked to low-carbon transition implementation.	Low to medium; digitalisation is often addressed more clearly than AI.	AI risks, accountability, and algorithmic oversight are rarely specified.
Responsible AI ethics frameworks	International	Principles, voluntary guidelines, transparency norms, human oversight expectations.	Relevant to AI used in energy planning, forecasting, consumer targeting, and system operation.	High at the general AI level but low at the energy-sector level.	Limited enforceability and insufficient attention to energy reliability and public-service obligations.
Digitalisation and smart energy governance frameworks	Regional and national	Data governance, interoperability rules, platform governance, cybersecurity requirements.	Central to smart grids, distributed energy resources, and demand flexibility.	Medium; algorithmic systems are implied but not always directly governed.	Platform power, data asymmetry, and algorithmic accountability remain insufficiently addressed.
Energy market and grid regulation	National and regional	Market rules, grid codes, reliability standards, licensing, monitoring, and compliance mechanisms.	Highly relevant because AI affects dispatch, trading, balancing, and congestion management.	Low; rules usually govern outcomes rather than AI decision processes.	Limited capacity to audit opaque AI systems and detect algorithmic manipulation or bias.
Energy justice and public participation frameworks	Local, national, and international	Consultation, equity assessment, procedural safeguards, community benefit mechanisms.	Important for ensuring that AI-enabled transitions do not deepen inequalities.	Low; AI is rarely treated as a justice-relevant governance object.	Insufficient mechanisms for public scrutiny of AI-enabled energy decisions.

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Sustainability transition policy frameworks	National, regional, and international	Mission-oriented policy, innovation policy, transition management, experimentation, policy learning.	Relevant to long-term directionality and coordination of low-carbon transitions.	Low to medium; AI may be included as an enabling technology.	Limited specification of how AI should be governed within transition experiments.

Cross-Cutting Analysis: Integration and Tensions

Recent empirical research has begun to quantify how governance conditions moderate the relationship between AI deployment and energy transition outcomes. Işık, Ongan, and Islam examined 33 OECD countries between 2002 and 2020 and found that while environmental factors positively affect energy transition, AI factors unexpectedly show a negative relationship, suggesting that high investment costs and implementation barriers may temporarily hinder progress [26]. Similarly, Park conducted a systematic review of socio-technical challenges in AI energy adoption, proposing an integrative governance framework built on four core principles—Trustworthiness, Sustainability, Equity, and Collaborative Adaptation—to move beyond piecemeal technical fixes toward lifecycle-based responsible deployment [27]. In the European context, a clustering analysis of 13 energy security indicators across EU member states demonstrated that AI-based policymaking approaches can produce more precise, explainable, and provable outcomes, yet the study also revealed significant heterogeneity in energy portfolios and institutional capacities that complicate unified governance frameworks [28].

Mismatches between conceptual models and policy frameworks

A major cross-cutting finding is that conceptual models often assign AI a transformative governance role, while policy frameworks remain too generic or too technically narrow to govern that role. AI-energy studies describe AI as capable of influencing transition trajectories through cleaner energy use, digital economy expansion, and innovation, yet the policy implications are often inferred rather than systematically developed [10, 22, 29]. Conversely, general AI ethics frameworks provide principles for responsible AI but rarely translate them into energy-specific institutional arrangements or regulatory instruments [5, 16]. This mismatch creates a governance deficit in which AI is expected to support transition complexity, but the mechanisms for ensuring accountability, legitimacy, and public control remain incomplete.

Unresolved tensions: efficiency vs. democracy, innovation vs. precaution

The literature reveals unresolved tensions between efficiency and democracy, innovation and precaution, and automation and human agency. Digitalisation studies show that smart energy systems and digital platforms may improve coordination, but they may also concentrate power in platform operators, data holders, and technical experts [12, 24]. AI ethics scholarship similarly warns that accountability cannot be secured through high-level principles alone when institutional responsibility, legal enforceability, and practical contestability are unclear [6, 15]. In energy transitions, these tensions are especially important because decisions about infrastructure, prices, access, and reliability affect citizens not merely as consumers but as participants in public systems.

The missing justice dimension in current approaches

The justice dimension remains insufficiently integrated into both conceptual models and policy frameworks for AI-enabled energy transition governance. Carley and Konisky show that clean energy transitions have major justice and equity implications, while Jenkins, Sovacool, and McCauley argue that energy justice should humanise socio-technical transitions by foregrounding ethical and distributional concerns [8, 9]. Yet much of the AI-energy literature continues to prioritise efficiency, forecasting, and system optimisation, leaving questions of recognition, participation, and unequal exposure to algorithmic harms underdeveloped [3, 18]. The result is a field in which AI is often assessed for what it can optimise, but not sufficiently for whom it empowers, whom it burdens, and who can challenge its decisions.

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Research Gaps and Limitations of Existing Work

Empirical deficit: from conceptual proposals to evidence

A recurring gap is the limited empirical grounding of claims about AI's capacity to improve energy transition governance. Several studies suggest that AI may support cleaner energy systems, accelerate transition processes, or reduce emissions, but these claims often remain at the level of association, conceptual expectation, or sector-wide modelling rather than governance evaluation [1, 10]. Reviews of AI in renewable energy and smart energy management demonstrate substantial technical maturity in forecasting, optimisation, and control, yet they provide less evidence about how AI changes institutional decision-making, regulatory accountability, or public legitimacy [3, 18]. Future research should therefore move beyond asking whether AI can optimise energy systems and examine whether AI-enabled governance arrangements actually improve coordination, transparency, justice, and adaptive capacity.

Theoretical under-development and conceptual silos

Theoretical development remains uneven because AI-energy studies, transition studies, and AI governance scholarship often operate in separate conceptual silos. Sustainability transitions research offers rich accounts of socio-technical change, regime resistance, policy mixes, and institutional directionality, but it rarely specifies how AI systems alter governance capabilities or authority relations within transitions [1, 7]. Conversely, AI governance scholarship provides ethical and regulatory principles but tends to treat application sectors as interchangeable domains rather than as historically specific infrastructures with distinct public obligations [5, 6]. This review identifies the need for middle-range theories that connect AI capabilities, energy-system characteristics, institutional design, and transition outcomes without reducing governance to either technical performance or abstract ethical compliance.

Governance of AI in the global south and diverse contexts

The reviewed literature is also limited by its tendency to generalise from contexts with advanced digital infrastructure, established energy regulators, and relatively high institutional capacity. Work on digitalisation and energy transition shows that digital economy development and government governance can shape transition outcomes, yet the implications for countries with weaker regulatory institutions, uneven digital access, or different political economies remain underexplored [23]. Studies of AI and energy transition at the global level help identify broad relationships, but they often lack the contextual depth needed to understand how AI governance varies across regions, utilities, market structures, and development pathways [29]. Future research should address how AI-enabled energy transition governance can be designed for diverse institutional contexts rather than assuming that governance models developed in high-income systems can be transferred without adaptation.

Temporal dynamics: governing a co-evolving technology and transition

Another limitation is that much of the literature treats AI governance and energy transition governance as relatively stable design problems, even though both are rapidly evolving. Historical work on the twin transitions of decarbonisation and digitalisation shows that energy and information systems co-evolve over long periods, with changing infrastructures, institutions, and social expectations [13]. At the same time, AI capabilities, data infrastructures, and digital energy platforms are developing faster than many regulatory systems can respond [12, 19]. The temporal governance challenge is therefore not simply to regulate current AI applications, but to design institutions capable of learning, revising, and contesting AI-enabled transition decisions as technologies and transition pathways change. **Figure 2** illustrates how AI governance for energy transitions must be adapted to diverse institutional contexts while remaining capable of revision as technologies, infrastructures, and transition pathways co-evolve over time.

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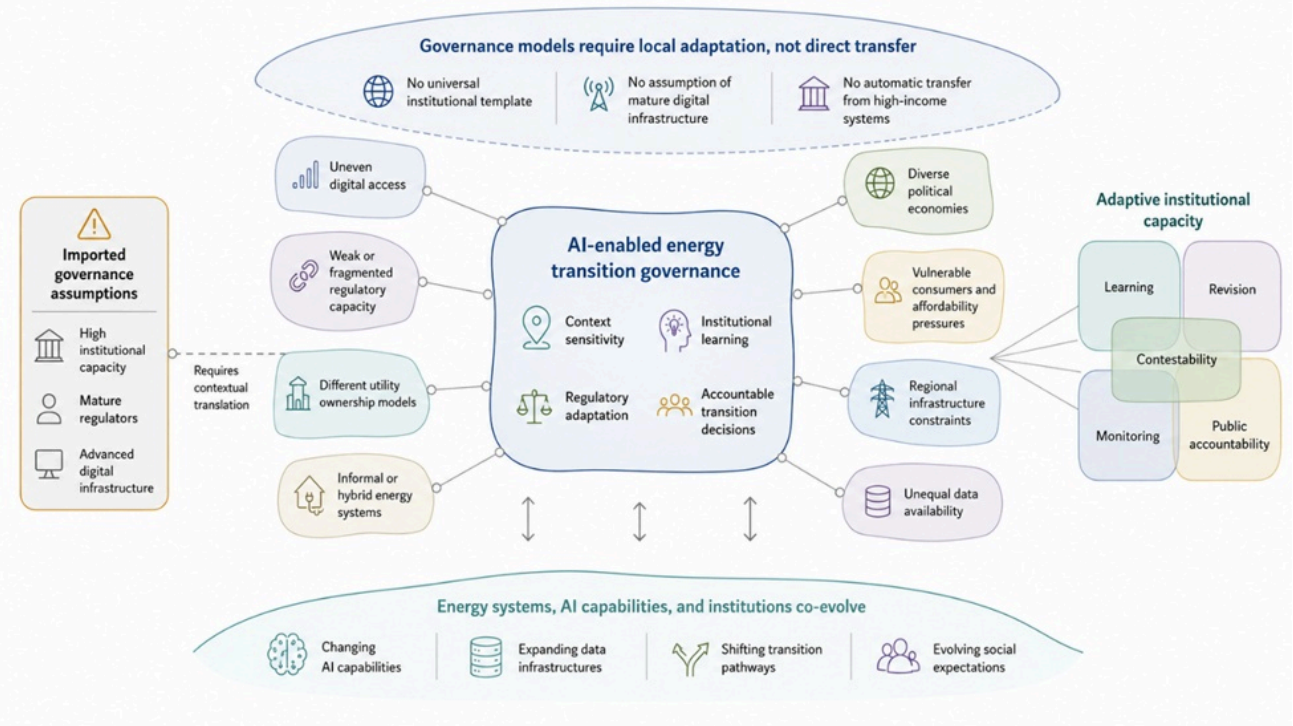

Figure 2. Context-Adaptive and Time-Responsive Governance for AI-Enabled Energy Transitions

Toward A Future Research Agenda

Building middle-range theories of AI and energy governance

Future research should develop middle-range theories that explain how specific AI capabilities interact with particular governance problems in energy transitions. For example, forecasting AI may affect anticipatory planning, optimisation AI may reshape resource allocation, and platform-based AI may alter market coordination and consumer participation [4, 20]. Such theories should be more precise than broad claims that AI accelerates transition, but more governance-oriented than narrow technical studies of model performance [17]. A useful research direction would be to connect AI functions to governance outcomes such as institutional learning, regulatory responsiveness, public accountability, system resilience, and transition legitimacy.

Designing adaptive and anticipatory governance for AI in energy

Future research should address adaptive and anticipatory governance mechanisms that can respond to changing AI capabilities and emerging transition risks. Responsible AI scholarship has already shown that ethical principles require operational mechanisms, institutional responsibilities, and procedures for resolving tensions among values [6, 16]. Energy transition research similarly emphasises experimentation, policy learning, and institutional adaptation as central to governing uncertain socio-technical change [7, 14]. The unresolved task is to design AI-energy governance arrangements that combine flexibility with accountability, allowing innovation while preventing opaque, unsafe, unjust, or democratically unaccountable uses of AI in critical energy systems.

Embedding justice and democracy into AI–energy governance research

A central priority is to embed justice, democracy, and public accountability into research on AI for energy transition governance. Energy justice scholarship shows that transition policies can distribute costs and benefits unequally, while digital energy futures may also reshape who has access to data, influence, and decision-making authority [8, 9]. Studies

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of energy democracy and digitalisation further suggest that digital tools can either widen participation or intensify technocratic control, depending on how they are governed [24]. As shown in **Table 3**, future research should treat justice and democracy not as secondary ethical add-ons but as core analytical dimensions of AI-enabled energy transition governance.

Table 3. Research Agenda for AI in Energy Transition Governance

Research Gap	Priority Research Questions	Suggested Methods	Policy/Governance Relevance
Weak empirical evidence on AI governance effects	How do AI-enabled tools change regulatory decisions, policy learning, market oversight, and stakeholder participation in energy transitions?	Comparative case studies, regulatory process tracing, interviews with regulators and system operators, institutional ethnography.	Helps determine whether AI improves governance capacity or merely automates existing institutional weaknesses.
Fragmented conceptual development	Which theories best explain the relationship between AI capabilities, transition dynamics, and governance authority?	Conceptual synthesis, theory-building reviews, interdisciplinary model comparison.	Supports more coherent policy design by linking AI functions to specific governance problems.
Limited energy-sector specificity in AI governance	What safeguards are required for AI used in grids, markets, utilities, demand response, and energy planning?	Legal analysis, sectoral regulatory mapping, expert deliberation, policy design workshops.	Enables translation of general AI principles into energy-specific regulatory instruments.
Neglect of justice and democracy	Who benefits, who is burdened, and who can contest AI-enabled energy transition decisions?	Participatory research, energy justice assessment, community-based inquiry, deliberative forums.	Strengthens legitimacy, procedural fairness, and public accountability in AI-enabled transitions.
Geographic bias and weak contextualisation	How do AI governance needs differ across Global South contexts, state-owned utilities, liberalised markets, and decentralised systems?	Cross-national comparison, regional case studies, institutional analysis, policy ethnography.	Prevents one-size-fits-all AI governance models and supports context-sensitive regulation.
Insufficient attention to platform power and data asymmetry	How do AI-enabled platforms redistribute control over energy data, flexibility markets, and consumer participation?	Platform governance analysis, political economy research, data governance audits.	Informs rules on data access, interoperability, consumer protection, and market power.
Lack of adaptive governance mechanisms	How can regulators update AI oversight as technologies, risks, and transition pathways evolve?	Foresight methods, scenario analysis, regulatory sandbox evaluation, anticipatory governance studies.	Supports governance systems that can learn without abandoning accountability or precaution.

Cross-sectoral learning and comparative research

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Cross-sectoral and comparative research should examine what energy governance can learn from other domains of AI regulation while also identifying where energy systems require distinctive safeguards. Cath's analysis of AI governance highlights ethical, legal, and technical challenges that cut across sectors, but energy systems add specific concerns related to reliability, infrastructure dependence, affordability, and public service [15]. Research on green buildings and smart buildings shows that AI governance questions also arise in built environments, where energy efficiency, occupant behaviour, data collection, and automation intersect [30, 31]. Comparative research across electricity, buildings, transport, finance, and public administration would help clarify which AI governance lessons are transferable and which must be redesigned for energy transition contexts.

Synthesis and Interdisciplinary Insights

The state of the field: a mosaic rather than a mature discipline

The state of the field is best described as a mosaic rather than a mature discipline. Energy economics studies examine whether AI contributes to energy transition or emissions reduction, while technical reviews document expanding applications in forecasting, smart energy management, and renewable integration [2, 3, 17]. Digitalisation and transition studies provide broader socio-technical perspectives, showing that AI is part of a wider transformation of infrastructures, markets, and institutional arrangements [12-14]. However, the field has not yet produced an integrated body of theory explaining how AI should be governed as part of energy transition rather than merely deployed within energy systems.

Pathways to interdisciplinary integration

Interdisciplinary integration requires stronger bridges between energy systems research, sustainability transitions, political economy, AI ethics, and regulatory studies. Energy justice research can help prevent AI-enabled transition governance from becoming narrowly technocratic, while responsible AI scholarship can provide language for transparency, accountability, and human oversight [5, 8]. At the same time, transition studies can situate AI within long-term processes of institutional change, power struggle, and system reconfiguration rather than treating it as a standalone innovation [1, 7]. A more integrated research field would examine AI simultaneously as technical infrastructure, governance instrument, political object, and site of democratic contestation.

Evaluation of the Review's Scope ond Method

Search strategy and thematic coding approach

This review used thematic coding to organise the 29 selected articles around conceptual models, policy frameworks, cross-cutting tensions, research gaps, and future research priorities. The coding approach was interpretive rather than statistical because the reviewed literature is conceptually diverse, spanning technical AI-energy studies, energy economics, digitalisation research, sustainability transitions, energy justice, and AI governance scholarship [5, 7, 17,20]. This strategy allowed the review to compare how different literatures frame AI's role in energy transition governance, rather than treating all studies as equivalent evidence units. Its main strength is conceptual integration, while its limitation is that it does not provide the reproducibility of a full systematic review protocol.

Quality assessment of the reviewed literature

Quality was assessed conceptually by examining each article's relevance, clarity of argument, theoretical contribution, governance significance, and fit with the review's scope. Technical reviews were considered valuable when they clarified AI's role in energy systems, but their limitations were noted when they paid limited attention to institutional or political implications [3, 4, 18]. Conceptual and governance-oriented articles were assessed for their ability to connect AI or digitalisation with transition dynamics, accountability, justice, and policy design [9, 14, 24]. This qualitative assessment

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allowed the review to distinguish between studies that merely mention governance and studies that substantively advance understanding of AI-enabled energy transition governance.

Potential biases in source selection

The review's source selection may reflect disciplinary and language biases because it prioritises English-language, peer-reviewed journal articles and excludes reports, standards, policy documents, and grey literature. This choice strengthens academic quality control but may underrepresent fast-moving policy initiatives, regulatory sandboxes, and practitioner debates that are not yet captured in journal publications. It may also overrepresent European and OECD-oriented perspectives, especially because much AI governance and energy transition scholarship is concentrated in institutions with strong publication visibility [15, 23]. The findings should therefore be read as a critical synthesis of the peer-reviewed academic literature rather than a complete inventory of all policy practice.

Limitations of the Review

The 29-source limit and its trade-offs

The fixed limit of 29 sources creates a trade-off between depth and breadth. It allows close thematic reading across AI-energy applications, digitalisation, transition studies, energy justice, and AI governance, but it necessarily excludes some specialised literatures on cybersecurity, electricity market regulation, public administration, and data protection [5, 12, 20]. The review therefore prioritises conceptual relevance to energy transition governance rather than exhaustive coverage of every AI application in the energy sector. This limitation is particularly important because AI-energy research is expanding rapidly across journals, disciplines, and policy domains.

A snapshot of a rapidly evolving domain

The conclusions of this review should be understood as a snapshot of a rapidly evolving domain rather than a settled assessment. AI capabilities, energy-system digitalisation, and policy debates have changed substantially across the 2017–2024 period, and further developments are likely to alter both risks and governance possibilities [11, 13]. Research on the whole-systems sustainability of digitalisation also suggests that new infrastructures, such as data centres and platform-based energy services, may generate governance concerns that are not fully anticipated by current frameworks [32]. Future reviews will need to revisit this field as AI becomes more deeply embedded in energy markets, grids, buildings, planning systems, and consumer-facing transition policies.

Conclusion

This review has shown that the literature on AI for energy transition governance is expanding but remains conceptually fragmented. AI is frequently presented as a tool for optimisation, forecasting, digital coordination, and low-carbon acceleration, yet the governance assumptions behind these claims are often underdeveloped. Policy frameworks, meanwhile, tend to rely on generic AI ethics principles or broad digitalisation agendas that do not fully address the specific obligations of energy systems. Significant research gaps remain around empirical evaluation, sector-specific regulation, justice, democracy, and adaptive governance.

The central challenge is to bridge the divide between conceptual ambition and policy capability. AI may support more responsive and coordinated energy transition governance, but it may also reinforce technocracy, concentrate power, obscure accountability, and reproduce inequalities. Whether AI strengthens or weakens transition governance will depend less on its technical sophistication alone than on the institutions, rules, participatory mechanisms, and accountability structures through which it is governed. This makes AI a socio-technical and political governance challenge rather than simply a computational resource.

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Future scholarship should develop a globally inclusive, justice-oriented, and interdisciplinary research programme on AI for energy transition governance. Such a programme should connect technical AI research with energy policy, transition studies, regulatory governance, political economy, and democratic theory. It should also attend to diverse institutional contexts, including those outside high-income and highly digitalised energy systems. Only through this broader approach can AI be governed in ways that support low-carbon transition while preserving accountability, public value, and social legitimacy.

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Conflict of interest

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Ethics statement

None

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