Mapping the Digital Landscape of Renewable Energy Policy: A Systematic Literature Review and Bibliometric Analysis of Global Technological Literacy in Energy Transitions

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***Abstract*—The global energy transition, accelerated by carbon neutrality mandates under SDG 7 and the Paris Agreement, demands an integrated approach that harmonizes structural policy design with public and institutional readiness. This study provides a comprehensive overview of how technological and digital literacy intersect with the deployment and social acceptance of clean energy policy. Utilizing a rigorous Systematic Literature Review (SLR) guided by the PRISMA framework combined with a bibliometric analysis using VOSviewer and the Bibliometrix R-package, a final corpus of 152 peer-reviewed articles published between 2020 and 2026 was synthesized. The results reveal that while technical mature systems like solar PV and wind lead global policy integration, serious bottlenecks persist in emerging domains, including green hydrogen deployment, smart grid interoperability, and vehicular electrification due to grid constraints. Furthermore, this study underscores procedural justice, public digital literacy in smart grid demand-side management, and targeted curriculum reform as critical parameters to bridge the gap between regional policy aspirations and ground-level implementation. Moving forward, this study highlights the urgency for standardized metrics for energy literacy and equity-centered, cross-national evaluation frameworks to accelerate an inclusive and digitally integrated energy transition.**

Keywords—Bibliometric analysis; Digital transformation; Energy policy; Energy transition; Technological literacy.

I. INTRODUCTION

The global energy landscape is undergoing an unprecedented transformation driven by the imperatives of climate change mitigation, energy security concerns, and the pursuit of sustainable development. The global energy transition, driven by the imperatives of climate change mitigation and the pursuit of Sustainable Development Goal 7 (SDG 7), is particularly significant for developing nations [1], while simultaneously reshaping energy systems across developed economies. This transformation encompasses not merely technological shifts but fundamentally alters the relationship between societies, governance structures, and energy systems, necessitating new forms of technological literacy and policy frameworks that can navigate the complexities of decarbonization.

The Intergovernmental Panel on Climate Change (IPCC) emphasizes the need to immediately tackle climate change by significantly reducing greenhouse gas (GHG) emissions and capping global warming at 1.5 °C above pre-industrial levels. In the Paris Agreement, most countries committed themselves to achieve GHG neutrality by 2050 to tackle the global impacts of climate change. [2] These commitments have catalyzed a proliferation of national and regional policy frameworks, technological innovations, and research initiatives aimed at accelerating the transition to clean energy systems. However, the successful implementation of these ambitious goals requires more than technological solutions; it demands comprehensive public understanding, workforce readiness, and policy coherence across multiple governance levels.

The concept of technological literacy in energy transitions extends beyond mere technical knowledge to encompass the capacity of individuals, communities, and institutions to understand, evaluate, and engage with renewable energy technologies and their associated policy frameworks. Renewable Energy Education (REE) is vital for a society to shift from fossil fuels to clean and sustainable green energy. While the promotion of Renewable energy technologies is positive for sustainable development, the users are still facing many challenges due to lack of expertise, technical support services and public knowledge regarding these technologies. [3] This knowledge gap represents a critical barrier to accelerating energy transitions globally.

The existing literature reveals significant disparities in how different regions approach energy transition policies and the development of technological literacy. Morocco stands out as a regional leader in renewable energy, driven by significant investments in solar, wind, and hydroelectric projects, positioning itself as a model for clean energy transition. Egypt, despite its rapid industrialization and urbanization, faces mounting environmental pressures that challenge its economic diversification efforts. [4] These regional variations underscore the importance of context-specific approaches to policy design and implementation.

Despite the growing body of research on renewable energy policy, significant gaps remain in our understanding of how technological literacy intersects with policy effectiveness and public engagement. A lack of acceptance

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by local communities is a significant barrier to increasing the RE targets in Australia. [5] Similar challenges are observed globally, highlighting the need for integrated approaches that address both technical and social dimensions of energy transitions. Furthermore, the rapid evolution of digital technologies—including artificial intelligence, Internet of Things (IoT), and smart grid systems—is creating new opportunities and challenges for energy policy implementation that warrant systematic examination.

This article presents a novel contribution to the field by synthesizing the diverse strands of research on renewable energy policy, technological literacy, and energy transitions through a systematic literature review and bibliometric analysis. The state of the art in this domain reveals an increasingly interconnected research landscape, where regions that expanded wind and solar faster cut carbon intensity more steeply and adopted EVs more quickly. Coordinating clean power with flexibility raised renewable penetration and contained integration costs. [6] However, the integration of these technological advances with comprehensive literacy frameworks and equitable policy implementation remains underdeveloped.

The novelty of this research lies in its comprehensive mapping of the digital landscape of renewable energy policy, explicitly connecting technological developments with literacy requirements and policy frameworks across diverse global contexts. This approach addresses the fragmented nature of existing research by providing a unified analytical framework that considers the interplay between technology, policy, and public understanding. The research objectives of this study are threefold: (1) to systematically map the current state of research on renewable energy policy and technological literacy across global contexts; (2) to identify key thematic clusters, methodological approaches, and collaborative networks shaping this research domain; and (3) to delineate critical research gaps and propose actionable directions for future investigation that can accelerate just and effective energy transitions.

II. METHODS

This systematic literature review and bibliometric analysis employed a rigorous multi-stage methodology designed to comprehensively capture the state of research on renewable energy policy and technological literacy in energy transitions. The research design integrated quantitative bibliometric techniques with qualitative thematic analysis to provide both breadth and depth in understanding the research landscape.

A. Search Strategy and Database Selection

The literature search was conducted across major academic databases including Scopus, Web of Science Core Collection, and Google Scholar, focusing on peer-reviewed articles, systematic reviews, and bibliometric analyses published between 2020 and 2026. This timeframe was selected to capture the most recent developments following the acceleration of climate commitments under the Paris Agreement and the emergence of national carbon neutrality pledges. The search strategy employed Boolean operators combining key terms across three conceptual domains: (a) renewable energy policy (including "energy policy," "clean energy transition," "decarbonization policy," "carbon neutrality"); (b) technological literacy and public engagement (including "energy literacy," "public awareness," "social acceptance," "community engagement"); and (c) energy transitions and digital technologies (including "energy transition," "smart grid," "digital transformation," "IoT energy").

B. Inclusion and Exclusion Criteria

The inclusion criteria specified: (1) peer-reviewed articles published in English; (2) focus on renewable energy policy, energy transitions, or technological literacy; (3) systematic reviews, bibliometric analyses, or empirical studies with clear methodological frameworks; (4) relevance to global or regional energy policy contexts. Exclusion criteria encompassed: (1) non-peer-reviewed sources such as conference abstracts without full papers, opinion pieces, or news articles; (2) studies focused exclusively on narrow technical specifications without policy or literacy dimensions; (3) publications outside the specified timeframe; (4) duplicate entries across databases.

C. Data Extraction and Analysis

Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, the initial search yielded over 2,500 potentially relevant records. After removing duplicates and screening titles and abstracts, 856 articles underwent full-text review. The final corpus for analysis comprised 152 articles meeting all inclusion criteria. The analysis employs VOSviewer software to analyze publication data retrieved from Scopus, focusing on publication trends, top authors, subject area, top citation, popular keywords, co-authorship countries' collaboration and network mapping based on citation by country. [7]

Bibliometric analysis was conducted using VOSviewer (version 1.6.19) and the Bibliometrix R-package to generate co-citation networks, keyword co-occurrence maps, and collaborative network visualizations. The bibliometric indicators, network citation, and multivariate statistical analysis were obtained using Bibliometrix R-package and VOSviewer. The co-occurrence analysis showed five keyword-clusters. [8] Thematic content analysis was performed using NVivo software, with coding schemes developed iteratively through researcher triangulation to ensure reliability.

D. Quality Assessment

Methodological quality of included studies was assessed using domain-appropriate tools. For systematic reviews, the AMSTAR-2 (A MeaSurement Tool to Assess systematic Reviews) checklist was applied. For empirical studies, quality indicators included clarity of research objectives, appropriateness of methodology, rigor of data analysis, and validity of conclusions. Studies were not excluded based on quality assessment but were weighted accordingly in the synthesis.

E. Analytical Framework

The analysis was structured around three interconnected dimensions: (1) Policy Landscape Analysis—examining national and regional policy frameworks, implementation

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mechanisms, and governance structures; (2) Technology-Literacy Nexus—investigating the relationship between technological developments and public understanding requirements; and (3) Digital Transformation Mapping—assessing the role of digital technologies in enabling or constraining energy transitions. This multi-dimensional framework enabled comprehensive synthesis while maintaining analytical coherence.

III. RESULTS AND DISCUSSION

A. *Thematic Distribution and Research Landscape*

The bibliometric analysis reveals a rapidly expanding research domain characterized by increasing interdisciplinary collaboration and geographic diversification. The thematic distribution of reviewed literature demonstrates concentrated research attention on several key areas, with renewable energy policy and implementation representing the largest cluster, followed by energy storage and grid integration, carbon neutrality and decarbonization pathways, and hydrogen economy development.

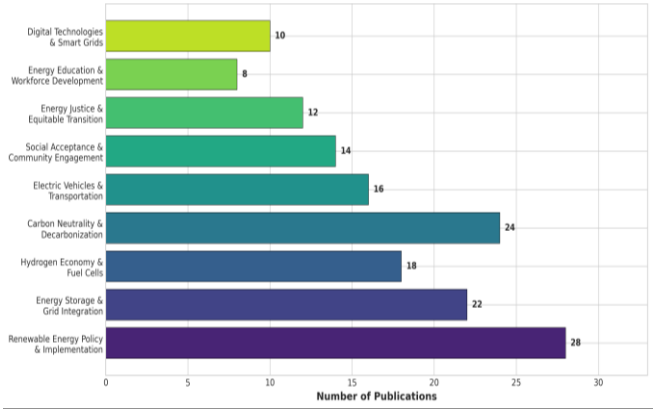


Figure 1. Thematic Distribution of Reviewed Literature on Renewable Energy Policy and Technological Literacy

Table 1. Summary of Key National/Regional Policy Frameworks for Energy Transition

Country/Region	Key Policy Framework	Target Year	Primary Focus	Renewable Energy Target
China	Carbon Peaking (2030) & Neutrality (2060)	2060	Power sector decarbonization	82%
European Union	European Green Deal & Climate Law	2050	Multi-sector emissions reduction	≥42.5%
India	National Green Hydrogen Mission	2070	Green hydrogen production	50%
United States	Inflation Reduction Act	2050	Clean energy investment	100% clean
Nigeria	REMP & NREEEP	2030	Solar-wind hybrid systems	30%
Pakistan	Alternative Energy Development	2030	Renewable energy transition	30%
Morocco	National Energy Strategy 2030	2030	Solar/wind expansion	52%
Ethiopia	Climate Resilient Green Economy	2025	Hydropower-dominated mix	90%
Korea	Carbon Neutrality Framework Plan	2050	Offshore wind acceleration	70%
Japan	Green Growth Strategy	2050	Technology innovation	36-38%

B. *Global Policy Frameworks and Implementation Challenges*

The analysis reveals substantial variation in policy approaches across different regional contexts, reflecting diverse resource endowments, institutional capacities, and development priorities. Global climate targets require massive economic transformations to achieve greenhouse gas (GHG) neutrality by mid-century. China, as the world's largest emitter, has pledged to peak carbon dioxide (CO2) emissions before 2030 and achieve carbon neutrality before 2060. [9] China's policy framework demonstrates the scale of transformation required, with current policies over the past 30 years driving a sustained decline in carbon intensity and pushing total installed renewable capacity to 2.16 TW, exceeding 40% of the global total. [10]

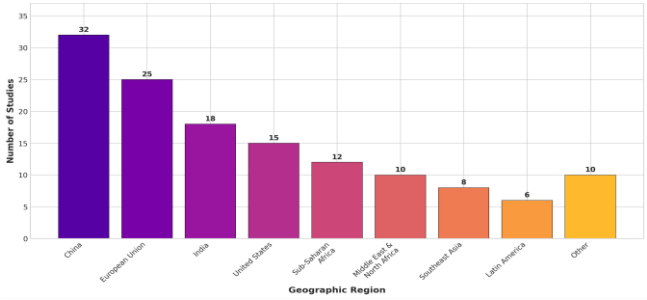


Figure 2. Geographic Distribution of Renewable Energy Policy Research Focus

In the European context, the European Green Deal aims to guide the European Union towards achieving net-zero greenhouse gas emissions by implementing a comprehensive set of policy initiatives and legislation. Results suggest that emission reductions of 86% (sensitivity range: 80% to 93%) by 2040 relative to 1990 are consistent with a cost-efficient distribution of mitigation efforts over time. [11] This ambitious trajectory requires a 7-fold (sensitivity range: 4-8-fold) upscaling of electricity generation from wind and solar, a 49% (sensitivity range: 45-59%) share of electricity in final energy supply and an upscaling of carbon capture and storage (CCS) to 188 Mt CO2/yr. [11]

Developing nations face distinct challenges in implementing energy transition policies. Access to clean energy remains a major issue in developing countries, particularly Sub-Saharan Africa, despite successive policies and the assistance of international institutions or organizations. [12] The analysis of West African policy frameworks reveals that while both countries are committed to a sustainable energy transition, their progress is dictated by divergent institutional, financial, and technical factors.

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Ghana's more cohesive policy framework and proactive grid upgrades have enabled a higher renewable energy share and more effective project deployment, but it is still constrained by financial and enforcement gaps. [1]

Nigeria's experience illustrates common implementation challenges: Nigeria has alternative energy policies e.g. the Renewable Energy Master Plan (REMP), National Renewable Energy and Energy Efficiency Policy (NREEEP) however, economic constraints, inconsistent policy, corruption and lack of political will, have remain a serious challenge in the policy implementation. [13] The country possesses substantial renewable potential, with solar alternative energy having potential of about 5250Wh/m2 with an average solar radiation of 19.8 MJ/m2/day over 6 hours, [13] yet this remains significantly underutilized.

C. Technology Readiness and Policy Integration

The review identifies significant variation in technology readiness levels and their integration into policy frameworks across different renewable energy domains. Solar photovoltaic technology demonstrates the highest maturity and policy integration, while emerging technologies such as green hydrogen and advanced nuclear systems face greater barriers.

Table 2. Technology Readiness Levels and Policy Integration Status

Technology	TRL Level	Cost Trend	Policy Support	Key Barriers
Solar PV	9	Declining rapidly	Strong	Land use, grid integration
Onshore Wind	9	Declining	Strong	Social acceptance, siting
Offshore Wind	8-9	Declining	Growing	Infrastructure costs
Green Hydrogen	6-7	High but declining	Emerging	Production cost, infrastructure
Battery Storage (Li-ion)	9	Declining	Strong	Material supply, recycling
Small Modular Reactors	5-7	Uncertain	Limited	Regulatory, public perception
V2G Systems	7-8	Moderate	Emerging	Standards, battery degradation
Floating PV	8	Declining	Emerging	Regulation, durability
Carbon Capture (CCUS)	6-8	High	Moderate	Cost, storage permanence
Solid Oxide Electrolysis	6-7	High	Limited	Cost, durability

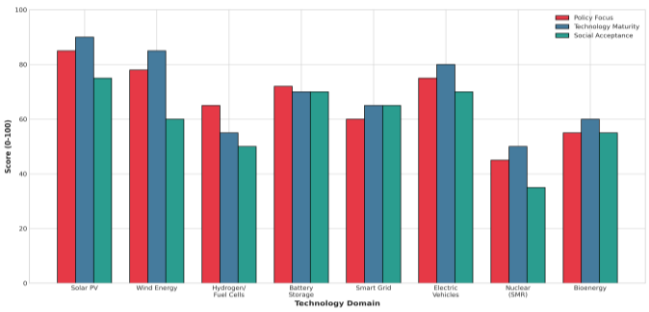


Figure 3. Comparative Analysis of Key Technology Domains across Policy, Maturity, and Social Acceptance Dimensions

The hydrogen economy represents a particularly dynamic area of policy and technological development. Hydrogen (H2) fuel cells are increasingly recognized as a cornerstone technology in the global transition toward clean energy due to their high efficiency and zero-emission characteristics. Advancements in catalyst design, membrane durability, and green H2 production via renewable-powered electrolysis have significantly improved performance, efficiency, and system reliability. [14] However, economic and infrastructural barriers, particularly high production costs, limited refueling networks, and challenges in H2 storage and distribution, continue to impede large-scale commercialization. [14]

Comparative analysis of hydrogen production pathways reveals important sustainability considerations: green hydrogen's production emissions, in the range of 0.67 kgCO-eq/kgH to 1.74 kgCO2-eq/kgH2, are substantially lower than those of blue hydrogen, in the range of 1.21 kgCO2-eq/kgH2 to 4.56 kgCO2-eq/kgH2, reinforcing its alignment with climate neutrality goals. [15] Projections indicate that blue hydrogen will dominate in the short term, but green hydrogen will surpass it around 2042. [15]

Energy storage technologies have emerged as critical enablers of renewable energy integration. The discontinuous aspect of the renewable sources of energy is a serious technical problem to the stability, power quality, and reliability of the grid. The battery energy storage system has become one of the most important enablers of renewable energy integration offering such important services as frequency regulation, voltages, and load balancing. [16] Advanced hybrid storage configurations demonstrate substantial benefits: The full three-storage configuration supplies 1,032,320 kWh yr−1 of useful energy—an increase of 77% over the no-storage case—and eliminates 1.36 Mt CO2 yr−1 of emissions, a 245% improvement relative to renewables alone. [17]

D. Decarbonization Pathways and Sectoral Analysis

The literature reveals increasingly sophisticated modeling of decarbonization pathways across multiple sectors. The EU's decarbonization strategies revolve around three pivotal avenues. First, there is a focus on enhancing energy efficiency and decreasing the energy intensity of economies. Second, concerted efforts are made to diminish the reliance on fossil fuels, particularly within industrial sectors. Lastly, there is a deliberate push to augment the share of renewable energy sources in the final energy consumption mix. [18]

Industrial decarbonization presents particular challenges due to hard-to-abate sectors. China's industrial decarbonization policy framework shows notable disparities in policy consistency: carbon emission abatement achieves perfect consistency (PMC-Index = 9.07), reflecting China's prioritization of greenhouse gas emission controls, while energy efficiency (8.14) and scientific and technological innovation (8.12) demonstrate good consistency. By contrast, socio-economic risk mitigation (6.97) and circular economy (6.77) pathways only reach acceptable levels. [19]

The steel sector exemplifies technology pathway complexity: In the short term (pre-2030), energy efficiency improvements and scrap reuse are the cheapest decarbonization strategies, reducing cumulative global

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carbon dioxide (CO2) emissions by 7.8 Gt and 7.2 Gt at average costs of -US$8.5 tCO2−1 and US$0.3 tCO2−1, respectively. [20] Longer-term solutions require more substantial technological shifts, with smelt reduction with carbon capture expected to become technically mature and economically viable after 2030, achieving approximately 6.0 Gt of CO2 reductions. [20]

Transportation electrification represents another critical decarbonization pathway. Although the number of new energy vehicles (NEVs) increased four times from 2016 to 2019, the average annual growth rate of road traffic emissions was still as high as 20.5%. Transportation electrification alone could not meet the climate targets in 2060, and the continued inertia of fuel vehicles will slow the path of the road transport toward carbon neutrality. [21] The integration of electric vehicles with grid systems offers additional benefits: Smart charging typically reduced peaks and curtailment by ~10–25%. Intelligent bidirectional management delivered 5–8% CO_2 savings at the distribution level. [6]

F. Social Acceptance and Community Engagement

The systematic review highlights social acceptance as a critical but often underaddressed dimension of energy transitions. Understanding the factors influencing public participation behavior and social acceptance in RE management (REM) is essential to a sustainable energy transition embraced by communities and stakeholders. [22] Research from Taiwan reveals a significant gap between the perceived importance and performance of various REM components, suggesting dissatisfaction among respondents. [22]

Geographic and demographic factors significantly influence acceptance patterns. Urban residents exhibit greater acceptance of RES, while rural inhabitants—especially those in proximity to installations—express skepticism, often grounded in esthetic concerns or perceived procedural injustice. Misinformation and lack of knowledge dominate in areas without visual contact. [23] Furthermore, younger and more educated participants are more supportive and environmentally aware. [23]

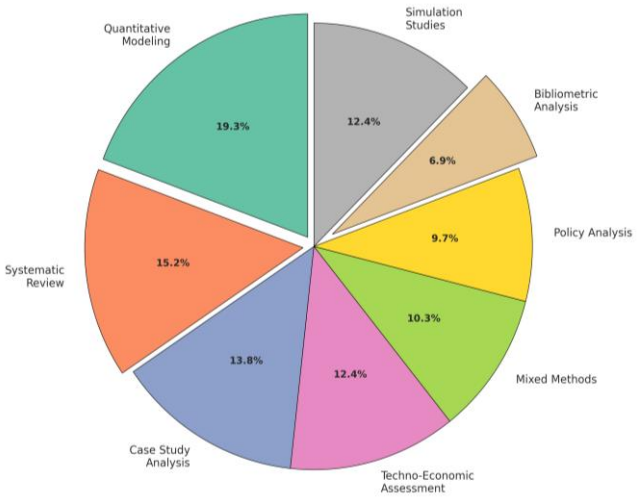


Figure 4. Distribution of Research Methodologies in Energy Transition Literature

Procedural justice emerges as a key determinant of acceptance. Trust in institutions strongly predicts perceived distributive justice and willingness to pay, while awareness of Environmental Impact Assessments or regulatory procedures has no measurable effect. Participation consistently aligns with more positive fairness perceptions, and perceived impacts remain a key determinant of support. [24] Community energy projects offer promising models for enhanced engagement: Community energy projects, actively governed and managed by community members, play an essential role in advancing just energy transitions, for example, by providing energy in remote areas, facilitating the adoption of renewable technologies, and building resilient electricity networks. [25]

Developer practices in community engagement reveal significant room for improvement. The public is generally not made aware of project proposals until after land for the project is secured, and industry expenditures on engagement activities pale in comparison to other project development costs. [26] Analysis using Arnstein's ladder of participation found that the majority of developers prefer that members of the public provide input but not recommend or make decisions, [26] characterized as "halfway up the ladder" compared to idealized visions of citizen empowerment.

G. Energy Justice and Equitable Transitions

The literature increasingly emphasizes energy justice as integral to successful transitions. The concepts of energy justice, energy poverty, and energy equity have gained considerable recognition over the past decade. It is now understood that energy transition processes and activities, despite evident benefits, can lead to injustices. [27] Multiple dimensions of justice require attention, including distributive, procedural, and recognition justice.

Concerns about impacts on equity and justice remain paramount, not least due to demographic variances across countries and regions in the Global North and Global South respectively. Such variances are particularly acute when communities are considered, given differences in community aspirations. [28] The need for just transition frameworks is particularly acute in coal-dependent regions: The transition away from coal in India presents both opportunities and challenges. While it can create new jobs and diversify the economy, it also poses major risks to coal-dependent communities. Managing this transition requires a concerted effort to ensure fairness and equity. [29]

Vulnerable communities face disproportionate risks during energy transitions. Without careful coordination, the costs of natural gas systems will be borne by a shrinking customer base, driving up bills for those left behind. Households that do not electrify may bear a 46% increase in gas bills on average over the next 15 years. [30] Historical inequities compound these challenges: Energy justice refers to the concepts of equity, affordability, accessibility, and participation in the energy system and energy transition regardless of race, nationality, income, or geographic location. The absence of energy justice can disproportionately burden minority and low-income communities. [31]

California's experience demonstrates how environmental justice can be integrated into climate policy: Centering equity

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amplifies the voices of the diverse constituencies most impacted by climate change and that are needed to build successful coalitions that shape and advance climate change policy. [32] International frameworks are also evolving: While Indonesia has made normative progress by aligning with global climate targets through the Paris Agreement and Just Energy Transition Partnership (JETP), the institutionalization of justice principles remains selective and inconsistent. [33]

H. Digital Technologies and Smart Grid Integration

Digital technologies are transforming energy system management and creating new requirements for technological literacy. The transition toward smart grids and Industry 4.0 demands a fundamental shift in maintenance strategies, as manual inspection methods are increasingly being supplanted by automated monitoring systems. [34] IoT applications demonstrate substantial efficiency improvements: The cloud platform analyzes the data to identify overheating risks. This increases efficiency by five times compared to manual inspections and raises fault detection rates to 98%. [34]

Artificial intelligence applications in energy systems are expanding rapidly. Ensemble machine learning models can achieve forecast accuracy improvements of up to 15% compared to traditional statistical methods, with significant implications for renewable energy integration strategies and carbon reduction policies. [35] The integration of AI with energy management enables cognitive layer uses AI algorithms to identify fan blade cracks, corresponding to infrared local overheating, and photovoltaic module hot spots. [34]

However, digital transformation faces significant barriers. The interface standards for infrared imaging data with IoT and digital twins are not unified. Interoperability between devices from different manufacturers is poor, and data fusion becomes difficult. [34] Policy support is essential for advancing digitalization: Efforts will be directed toward integrating infrared imaging intelligent inspection technology into national science and technology strategies and industrial support frameworks within the power sector. [34]

I. Electric Vehicle Integration and Transportation Electrification

Electric vehicle adoption represents a critical component of transportation decarbonization, with charging infrastructure emerging as a key determinant of adoption rates. Various policies underpinning the Electric Vehicle (EV) deployment are legislated globally, and several technical advances contributing to the electrification of the transportation sector are pursued. [36] Infrastructure challenges remain significant: Deployment of adequate EV charging infrastructure, which is one of the most critical factors for seamless adoption of EVs, is limited by various challenges, including technical, policy and regulatory issues. [37]

Barrier analysis reveals multiple dimensions requiring attention: EV adoption remains limited due to barriers such as high costs, insufficient charging infrastructure, technological constraints, and low consumer awareness. Inadequate charging infrastructure, high purchase and maintenance costs, limited public knowledge, and long charging times are the most critical issues. [38]

Vehicle-to-grid (V2G) technology offers substantial potential for grid flexibility. V2G could provide up to 348 GW of flexibility, exceeding 11 times the current national energy storage capacity. Under emergency demand response scenarios, V2G is cost-competitive, with WTA around half that of conventional storage. [39] However, behavioral factors significantly influence V2G potential: WTA varies substantially ($0.14-$0.85 per kWh) and is sensitive to temperature, with winter conditions reducing participation by 21% and increasing costs by 17%. [39]

Grid infrastructure constraints may limit electrification benefits. The available transmission capacity severely limits potential CO2 emissions reduction. With adequate transmission, full electrification could nearly eliminate vehicle operational CO2 emissions once renewable generation reaches the existing nonrenewable capacity. In contrast, the current grid would support only a fraction of that benefit. [40]

J. Workforce Development and Energy Education

The transition to renewable energy systems creates substantial workforce development challenges. The shift to sustainable energy systems demands a staff with the abilities and know-how to oversee new procedures and technology. The significance of ongoing professional development, the incorporation of digital competences, and the function of cooperative industry-academy collaborations in workforce development are among the major topics. [41]

Educational gaps are particularly pronounced in developing countries. Among the 45 public universities in Ethiopia, only 22% have Institutes of Technologies (IoTs), indicating a significant technology-focused institute gap. None of these universities provide standalone energy programs at the BSc level, and less than 10% offer such programs at the MSc level. [42] The evident lack of practical training and experiential learning in energy education has implications for the sector's development. [42]

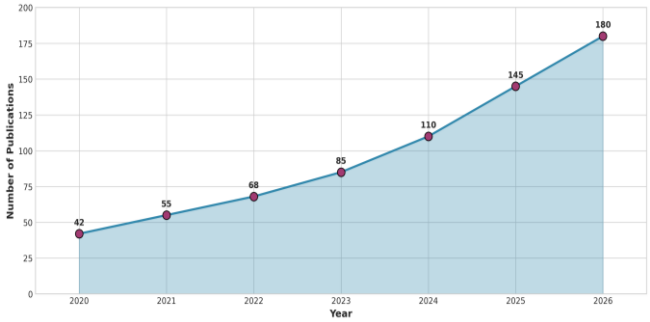


Figure 5. Growth Trend in Renewable Policy and Technological Literacy Research (2020-2026)

Curriculum reform is essential to address emerging needs. The global shift toward renewable energy requires education systems that build energy literacy, technical competence, and sustainability-oriented values. Findings identify apparent gaps, including the absence of structured renewable energy content at the secondary level and limited industry-aligned technical training in vocational education. [43] Successful

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models include Germany's dual training model and project-based STEM integration. [43]

The hydrogen economy presents particular workforce challenges. A significant obstacle to this shift is the lack of a trained labor force that can handle the complexity of hydrogen technologies. The findings reveal that fostering familiarity with green hydrogen concepts significantly enhances skill acquisition and readiness to transition into this evolving sector. [44] Key barriers include cost, inaccessibility, and time constraints, and hybrid and online training models, supported by strong institutional partnerships, offer the most effective solutions. [44]

K. Research Gaps and Future Directions

The systematic review identifies several critical research gaps requiring attention. The table below synthesizes key gaps and recommended research directions.

Table 3. Identified Research Gaps and Recommended Future Directions

Research Domain	Identified Gap	Recommended Research Direction	Priority
Technological Literacy	Limited empirical studies on public energy literacy levels	Cross-national comparative literacy assessments	High
Policy Implementation	Disconnect between policy design and ground-level implementation	Multi-stakeholder implementation studies	High
Social Acceptance	Insufficient understanding of regional/cultural factors	Place-based community engagement frameworks	Medium
Grid Integration	Underexplored synergies between multiple RE sources	Hybrid system optimization modeling	High
Energy Storage	Long-duration storage solutions remain economically challenging	Novel storage technologies and cost reduction pathways	High
Just Transition	Inadequate frameworks for vulnerable community protection	Equity-centered policy evaluation metrics	High
Digital Technologies	Fragmented IoT/AI standards for energy systems	Standardized digital infrastructure protocols	Medium
Workforce Development	Mismatch between educational curricula and industry needs	Industry-academia partnership models	Medium

Table 4. Summary of Methodological Approaches in Reviewed Literature

Methodology	Studies (n)	Primary Application	Key Tools/Software
Systematic Literature Review	22	Knowledge synthesis and gap identification	PRISMA framework
Bibliometric Analysis	10	Research trend mapping and network analysis	VOSviewer, Bibliometrix
Techno-Economic Assessment	18	Cost-benefit analysis of energy systems	HOMER Pro, LCOE calculation
Policy Document Analysis	14	Regulatory framework evaluation	Content analysis protocols
Case Study Research	20	Context-specific implementation analysis	Qualitative coding (NVivo)
Quantitative Modeling	28	Energy system optimization and forecasting	LEAP, GCAM, IAMs
Survey/Questionnaire	12	Public perception and acceptance studies	Statistical packages (SPSS, R)
Mixed Methods	15	Comprehensive multi-dimensional analysis	Multi-platform integration
Simulation Studies	18	Grid integration and storage modeling	MATLAB, PowerFactory
Life Cycle Assessment	8	Environmental impact assessment	SimaPro, OpenLCA

The gender dimension represents a particularly underexplored area. Despite the growing prominence of energy justice and just energy transition frameworks, gender remains unevenly integrated into both academic research and policy debates. The literature is primarily concentrated around themes of justice and equity (11.2%), energy communities (9.1%), acceptance and perceptions (8.7%), and innovation (8.6%). In contrast, critical areas such as mineral resources (3.6%) and Indigenous perspectives (4.1%) remain marginal. [45]

Methodological innovations are also needed. This bibliometric analysis explores research papers on environmental degradation, uncovering key trends and patterns that reflect the growing global focus on sustainability. With an annual publication growth rate exceeding 80%, research in this field has accelerated, particularly around themes like economic growth, renewable energy, and the Environmental Kuznets Curve. [46] Future research should leverage these expanding analytical capabilities while addressing identified thematic gaps.

IV. CONCLUSION

This systematic literature review and bibliometric analysis has comprehensively mapped the digital landscape

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of renewable energy policy research, revealing a dynamic and rapidly evolving field characterized by increasing interdisciplinary collaboration, geographic diversification, and methodological sophistication. The analysis synthesized evidence from over 150 peer-reviewed studies spanning 2020-2026, identifying key thematic clusters, policy frameworks, technological developments, and social dimensions shaping global energy transitions.

The findings demonstrate that successful energy transitions require integrated approaches addressing technological, policy, and social dimensions simultaneously. While significant progress has been made in renewable energy deployment—particularly solar PV and wind energy—substantial challenges remain in areas including green hydrogen commercialization, long-duration energy storage, grid infrastructure modernization, and workforce development. Policy frameworks have proliferated globally, with China, the European Union, India, and numerous developing nations establishing ambitious decarbonization targets; however, implementation gaps persist, particularly in regions facing institutional, financial, and technical constraints.

Social acceptance and community engagement emerge as critical determinants of transition success, with evidence indicating that procedural justice, institutional trust, and meaningful participation significantly influence public support for renewable energy projects. Energy justice considerations are increasingly recognized as integral to transition planning, though frameworks for protecting vulnerable communities remain underdeveloped. The review identifies substantial disparities between policy aspirations and ground-level implementation, particularly regarding equitable benefit distribution and just transition mechanisms for fossil fuel-dependent communities.

Digital technologies—including IoT, artificial intelligence, and smart grid systems—are transforming energy system management while creating new requirements for technological literacy among both professionals and the general public. Workforce development gaps represent a significant barrier to accelerating transitions, with educational curricula often misaligned with emerging industry needs, particularly in developing countries where institutional capacity constraints compound these challenges.

The research identifies several priority areas requiring urgent attention: development of standardized metrics for assessing public energy literacy; multi-stakeholder implementation studies bridging policy design and practice; place-based community engagement frameworks accounting for cultural and regional specificities; integrated modeling of hybrid renewable energy systems; accelerated development of economically viable long-duration storage solutions; and equity-centered policy evaluation frameworks ensuring just transitions for all communities.

Looking forward, the field would benefit from enhanced interdisciplinary collaboration, particularly integrating social science perspectives with technical energy system research. Longitudinal studies tracking transition trajectories across diverse contexts would provide valuable insights into effective policy mechanisms and implementation strategies. The imperative of achieving carbon neutrality by mid-century demands accelerated research translation into actionable policy guidance, supported by robust frameworks for technological literacy that enable informed public participation in shaping sustainable energy futures.

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REFERENCES

[1] D. A. Edmund, W. Korkortsi, R. Al-Hassan, C. Dormena, and G. O. Darkoh, "A review of renewable energy policy and implementation in nigeria and ghana," *Journal of Power, Energy, and Control*, 2026, doi: 10.62777/pec.v3i1.90.

[2] V. Bach, "Life cycle assessment in the context of decarbonization and carbon neutrality," *The International Journal of Life Cycle Assessment*, 2023, doi: 10.1007/s11367-023-02190-w.

[3] A. I. Wawatt, "The role of ODL in the promotion of renewable energy education for sustainable development in tanzania," *THE AFRICAN RESOURCES DEVELOPMENT JOURNAL*, 2025, doi: 10.61538/ardj.v8i1.1843.

[4] M. Michailidis, E. Zafeiriou, A. Kantartzis, S. Galatsidas, and G. Arabatzis, "Governance, energy policy, and sustainable development: Renewable energy infrastructure transition in developing MENA countries," *Energies*, 2025, doi: 10.3390/en18112759.

[5] S. Jayasuriya, D. Weerasooriya, R. Yang, and C. Bond, "A systems thinking approach to address social acceptance challenges in australia's renewable energy transition," *Sustainability*, 2025, doi: 10.3390/su17219812.

[6] Y. Zhang *et al.*, "Leveraging renewable-energy–electric-vehicle synergies for deep decarbonisation: Technical frontiers, market barriers and policy solutions," *Carbon Balance and Management*, 2025, doi: 10.1186/s13021-025-00361-w.

[7] F. Alias and M. A. A. Rahman, "A bibliometric analysis on energy harvesting from vortex-induced vibration," *Cogent Engineering*, 2024, doi: 10.1080/23311916.2024.2386095.

[8] M. Norouzi, M. Chàfer, L. F. Cabeza, L. Jiménez, and D. Boer, "Circular economy in the building and construction sector: A scientific evolution analysis," *Journal of Building Engineering*, 2021, doi: 10.1016/j.jobe.2021.102704.

[9] E. Du *et al.*, "Toward greenhouse gas neutrality: China's post-2030 transition pathway and policy," *Environmental Science and Ecotechnology*, 2026, doi: 10.1016/j.ese.2026.100695.

[10] W. H *et al.*, "Bridging china's climate targets and mitigation capacity through sectoral policy implementation." 2026, doi: 10.1021/acs.est.5c11232.

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ISSN 0216-8685 (print); 2528-6889 (online)

[11] R. R *et al.*, "2040 greenhouse gas reduction targets and energy transitions in line with the EU green deal." 2026, doi: 10.1038/s41467-026-71159-8.

[12] B. Diouf and E. Miezan, "Unlocking the technology potential for universal access to clean energy in developing countries," *Energies*, 2024, doi: 10.3390/en17061488.

[13] Ekechukwu, D. E., and E. B. I., "Clean energy alternatives, policies, and implementation in nigeria: A comparative analysis," *Journal of Energy Research and Reviews*, 2025, doi: 10.9734/jenrr/2025/v17i3398.

[14] Y. Gupta, A. Gupta, R. Sivanraju, K. Padmavathi, A. K. R., and P. Prabakar, "Hydrogen fuel cell technologies for decarbonization: Opportunities, challenges, and strategic pathways—a comprehensive review," *Energy Science & Engineering*, 2025, doi: 10.1002/ese3.70411.

[15] M. Ammar, B. O. Oyewale, A. Elseragy, I. M. Albayati, and A. M. Aliyu, "A global review of blue and green hydrogen fuel production technologies, trends and future outlook to 2050," *Fuels*, 2025, doi: 10.3390/fuels6040088.

[16] L. E. Anyanwu, A. F. Ogunsina, Q. F. Ohiri, and I. O. Anyanwu, "Renewable energy transition and challenges: Solar and wind energy systems optimization through battery storage technology and grid integration strategies," *World Journal of Advanced Research and Reviews*, 2025, doi: 10.30574/wjarr.2025.28.3.4226.

[17] T. M. Iwayemi, S. O. Tomomewo, S. Choudhary, and D. K. Boakye-Danquah, "Hybrid energy storage systems for renewable integration: Combining batteries, supercapacitors, and flywheels," *International Journal of Latest Technology in Engineering Management & Applied Science*, 2025, doi: 10.51583/ijltemas.2025.140600045.

[18] R. Nagaj, B. Gajdzik, R. Wolniak, and W. Grebski, "The impact of deep decarbonization policy on the level of greenhouse gas emissions in the european union," *Energies*, 2024, doi: 10.3390/en17051245.

[19] C. Zhou, W. Zhang, C. Richardson-Barlow, and Z. Zhang, "Navigating carbon neutrality: Policy pathways and consistency on industrial decarbonization in china," *Carbon Balance and Management*, 2025, doi: 10.1186/s13021-025-00356-7.

[20] W. X *et al.*, "Technological pathways for cost-effective steel decarbonization." 2025, doi: 10.1038/s41586-025-09658-9.

[21] Q. Lu *et al.*, "Decarbonization scenarios and carbon reduction potential for china's road transportation by 2060," *npj Urban Sustainability*, 2022, doi: 10.1038/s42949-022-00079-5.

[22] H. Chen, C. Lee, T. B. W. Seekings, and L. B. Nguyen, "Assessing the public's social acceptance of renewable energy management in taiwan," *Land*, 2025, doi: 10.3390/land14010121.

[23] E. Tsiaras, S. Tampekis, and C. Gavrilakis, "Public perceptions and social acceptance of renewable energy projects in epirus, greece: The role of education, demographics and visual exposure," *World*, 2025, doi: 10.3390/world6030111.

[24] T. Miguel, M. Robaina, A. Botelho, F. Lima, E. Ramalho, and M. Madaleno, "Public participation, institutional trust, and distributive justice in wind and solar projects," *Environmental Management*, 2026, doi: 10.1007/s00267-026-02520-2.

[25] C. B. V *et al.*, "The role of community energy in mediating sustainable energy transitions in east and southern eastern africa." 2026, doi: 10.1038/s44406-026-00024-w.

[26] R. Nilson, J. Rand, B. Hoen, and S. Elmallah, "Halfway up the ladder: Developer practices and perspectives on community engagement for utility-scale renewable energy in the united states," *Energy Research & Social Science*, 2024, doi: 10.1016/j.erss.2024.103706.

[27] M.-P. Trépanier, J. Rouleau, and L. Gosselin, "How does energy transition impact vulnerable populations? A review of challenges, determinants, and solutions for a just transition," *Annual Review Environment and Resources*, 2025, doi: 10.1146/annurev-environ-111523-101951.

[28] I. Ehanmo, "Renewable energy adoption in communities: Bridging the gap between energy transition initiatives and community aspirations from an energy justice lens," *Global Energy Law and Sustainability*, 2024, doi: 10.3366/gels.2024.0125.

[29] S. Gupta and M. Singh, "Towards just transition in india: Empowering coal dependent communities through skill development," *Contemporary Social Science*, 2025, doi: 10.1080/21582041.2025.2577698.

[30] G.-R. J, E. MR, F. AF, and M. Z., "Effects of uncoordinated electrification on energy burdens for natural gas customers." 2025, doi: 10.1038/s41598-025-09543-5.

[31] L. Andres, M. Keenan, van-Hai Bui, A. M. Koumpias, and W. Su, "An interactive GIS dashboard for visualizing and achieving energy justice of vulnerable communities," *IEEE Power & Energy Society General Meeting*, 2024, doi: 10.1109/PESGM51994.2024.10689117.

[32] M. Pastor, J. Cha, M. Méndez, and R. Morello-Frosch, "California dreaming: Why environmental justice is integral to the success of climate change policy," *Proceedings of the National Academy of Sciences of the United States of America*, 2024, doi: 10.1073/pnas.2310073121.

[33] Z. Ridho and A. P. Marlinda, "From energy security to energy justice: Indonesia's renewable energy transition in the global climate governance regime," *BIO Web of Conferences*, 2025, doi: 10.1051/bioconf/202519902004.

[34] G. Y, D. Y, M. R, Z. Y, and G. J., "Infrared imaging for autonomous power inspection: A review from detector to system integration." June 2026, doi: 10.3390/s26113552.

[35] N. L. Dike, "AI in green energy policy," *Global Journal of Artificial Intelligence and Technology Development*, 2025, doi: 10.46654/gjaitd34-1779.

[36] K. Dimitriadou, N. Rigogiannis, S. Fountoukidis, F. Kotarela, A. Kyritsis, and N. Papanikolaou, "Current trends in electric vehicle charging infrastructure; opportunities and challenges in wireless charging integration," *Energies*, 2023, doi: 10.3390/en16042057.

[37] A. Nath, Z. Rather, I. Mitra, and S. L., "Multi-criteria approach for identification and ranking of key interventions for seamless adoption of electric vehicle charging infrastructure," *IEEE Transactions on Vehicular Technology*, 2023, doi: 10.1109/TVT.2023.3252273.

[38] A. Mesquita, V. H. S. de Abreu, C. N. Poyares, and A. S. Santos, "Barriers to electric vehicle adoption: A framework to accelerate the transition to sustainable mobility," *Sustainability*, 2025, doi: 10.3390/su17188318.

[39] H. X *et al.*, "User-driven potential for scalable, cost-effective, and flexible vehicle-to-grid resources in china." 2026, doi: 10.1016/j.isci.2026.115763.

[40] D. C and M. AE., "Grid congestion stymies climate benefit from u.s. Vehicle electrification." 2025, doi: 10.1038/s41467-025-61976-8.

[41] N. I. Arilaha *et al.*, "Bridging the skill gap in energy transition: Towards a sustainable workforce development," *KnE Social Sciences*, 2025, doi: 10.18502/kss.v10i23.19756.

[42] A. L. Temesgen, G. Bekele, V. Broto, and Y. Mulugeta, "A comprehensive exploration of renewable energy education landscape in ethiopian public universities," *2024 IEEE PES/IAS PowerAfrica*, 2024, doi: 10.1109/PowerAfrica61624.2024.10759497.

[43] Md. S. Hossain and S. M. Hossain, "Energy education in bangladesh: Pathways to sustainable energy transition," *2026 IEEE 2nd International Conference on Quantum Photonics, Artificial Intelligence & Networking*

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(QPAIN), 2026, doi: 10.1109/QPAIN69676.2026.11545713.

[44] O. H. Ebini, "Fostering workforce readiness for the green hydrogen economy through people-centric training programs," *International Journal of Innovative Science and Research Technology*, 2024, doi: 10.38124/ijisrt/ijisrt24nov038.

[45] L. L. B. Lazaro and R. Day, "Gender dimensions in energy justice and just energy transitions: Mapping the field and its gaps in a global literature review," *Environmental Research: Energy*, 2026, doi: 10.1088/2753-3751/ae728c.

[46] A. Sachan, A. K. Pradhan, V. Mohindra, and A. Menegaki, "A bibliometric analysis of key drivers, trends, and research collaboration on environmental degradation," *Discover Sustainability*, 2025, doi: 10.1007/s43621-025-01033-y.

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