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Analysis of Drivers and Barriers to Sustainable Renewable Energy Transition in Iran Using the Multi-Level Perspective Approach

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ABSTRACT

The transition to renewable energy has emerged as a key priority for energy systems worldwide due to its critical role in achieving sustainable development, enhancing energy security, and mitigating the impacts of climate change. Despite Iran's considerable potential in renewable energy resources, the development of these resources faces numerous challenges. This study aims to identify and analyze the key drivers and barriers influencing the transition to renewable energy in Iran using the multi-level perspective (MLP) approach. In this regard, after extracting relevant data, the factors affecting energy transition were categorized across three analytical levels of landscape, regime, and niche, and their roles as either drivers or barriers were examined. The findings identified 58 influential factors affecting the energy transition in Iran, including 20, 22, and 16 factors at the landscape, regime, and niche levels, respectively. The results showed that landscape-level factors, such as climate change, global decarbonization trends, energy security concerns, and international pressures, mainly act as external drivers creating momentum for the transition. At the regime level, structural barriers, including fossil fuel dependence, energy subsidies, weak financing mechanisms, institutional fragmentation, regulatory instability, and infrastructure limitations, were found to significantly constrain the diffusion of renewable energy. The niche level represented major transformative capacities through renewable energy technologies, research and development activities, knowledge-based companies, pilot projects, and technological innovation capabilities. However, these capacities remain limited by financial constraints and weaknesses in the technological supply chain. Furthermore, the findings demonstrated that the identified factors affect multiple sustainability dimensions, including economic, environmental, social, technological, and institutional and policy aspects.

Keywords: *Energy transition; Renewable energy; Multi-level perspective; Sustainable development; Drivers and barriers; Iran.*

1. Introduction

The transition from fossil-fuel-based energy systems toward renewable and low-carbon alternatives has become a central component of contemporary sustainability agendas. Energy systems are deeply embedded in economic production, technological infrastructures, institutional arrangements, consumption patterns, and social practices; consequently, transforming them requires substantially more than the substitution of one energy technology for another. Sustainability transitions involve long-term and multidimensional processes through which established configurations of technologies, markets, institutions, infrastructures, policies, cultural meanings, and user practices are gradually restructured. The sustainability transitions literature has therefore developed as an interdisciplinary field concerned with explaining how fundamental changes in socio-technical systems emerge, gain momentum, encounter resistance, and eventually become institutionalized (Markard et al., 2012). Within this perspective, the energy transition represents not only an environmental response to climate change but also a structural transformation involving technological innovation, institutional adaptation, economic restructuring, and changes in the relationships among governments, industries, consumers, and knowledge-producing organizations (Köhler et al., 2019).

Energy transitions are particularly complex because incumbent energy systems possess considerable technological, economic, institutional, and political stability. Existing infrastructures are associated with substantial sunk investments, established supply chains, regulatory frameworks, organizational routines, professional capabilities, and consumer practices that tend to reproduce prevailing patterns of energy production and consumption. Such interdependencies create path dependence and lock-in, making radical changes difficult even when technically viable alternatives are available. Historical analysis of electricity-system transformation has shown that energy transitions emerge through the co-evolution of technologies, institutional rules, actor networks, policy priorities, and societal expectations rather than through technological progress alone (Verbong & Geels, 2007). Consequently, understanding renewable-energy transition requires analytical approaches capable of examining both the emergence of innovative alternatives and the structural forces that preserve incumbent energy systems.

The Multi-Level Perspective (MLP) has become one of the most influential frameworks for addressing this analytical challenge. The MLP conceptualizes socio-technical transitions through interactions among three analytical levels: the socio-technical landscape, the established regime, and technological or social niches. The landscape encompasses relatively broad and slowly changing external conditions, such as macroeconomic trends, demographic transformations, cultural values, geopolitical developments, environmental pressures, and global policy shifts. The regime consists of the dominant technologies, institutions, regulations, infrastructures, markets, user practices, and organizational arrangements that stabilize the existing system. Niches, in contrast, constitute protected or emerging spaces in which alternative technologies, business models, practices, and organizational forms can be developed, tested, learned from, and improved. Transition occurs when pressures and developments across these levels interact in ways that destabilize incumbent arrangements and create opportunities for niche innovations to diffuse and reshape the dominant regime (Geels, 2017).

An important contribution of the MLP is its rejection of linear interpretations of technological change. Socio-technical transitions do not necessarily proceed through a predictable sequence from invention to diffusion and replacement. Instead, different configurations of landscape pressure, regime instability, and niche maturity may produce different transition pathways. Geels and Schot demonstrated that interactions among these levels can generate processes such as transformation, technological substitution, reconfiguration, or de-alignment and re-alignment, depending on the timing and intensity of external pressures and the development of alternatives (Geels & Schot, 2007). This insight is especially relevant to energy systems in which incumbent technologies retain strong economic and institutional advantages while emerging renewable technologies simultaneously benefit from environmental pressures, technological improvements, and changing societal expectations. The trajectory of an energy transition therefore depends not simply on whether renewable alternatives exist, but on whether the wider socio-technical environment enables those alternatives to challenge, complement, or transform established structures.

More recent developments in transition theory have also emphasized the importance of actors and agency. Earlier applications of the MLP were sometimes criticized for placing greater emphasis on structural dynamics than on the strategies and capabilities of individual and collective actors. Subsequent theoretical refinements have demonstrated that transitions are actively shaped by entrepreneurs, policymakers, incumbent firms, civil-society organizations, consumers, researchers, and other actors who interpret structural pressures, mobilize resources, form coalitions, influence institutional rules, and create or resist new transition pathways. Agency is therefore multidimensional and operates through strategic action, learning, interpretation, institutional entrepreneurship, and network formation (Geels, 2020). This perspective is particularly important in countries where institutional fragmentation, contested policy priorities, resource constraints, and entrenched economic interests may mediate the relationship between technological potential and actual deployment.

The growing emphasis on governance has similarly expanded the analytical scope of sustainability-transition research. Transition processes involve political choices concerning the allocation of resources, the design of incentives, regulation of markets, protection or withdrawal of support for incumbent technologies, and creation of favorable conditions for emerging alternatives. Innovation policy can influence transitions by nurturing niches, stimulating experimentation, facilitating learning, coordinating actors, and gradually changing the institutional environment in which established regimes operate (Kern, 2012). At the same time, contemporary transition scholarship increasingly recognizes that governance strategies must respond to different phases of systemic transformation. The movement toward net-zero energy systems may involve successive phases of innovation emergence, expansion and restructuring of the electricity sector, diffusion of low-carbon solutions into additional sectors, and eventual system-wide decarbonization, with each phase requiring different combinations of technological, institutional, market, and policy interventions (Markard & Rosenbloom, 2023).

Technological diffusion itself should also be understood as a process of societal embedding rather than merely increasing the number of installed technologies. New energy technologies become transformative only when they are incorporated into infrastructures, markets, regulations, organizational routines, user practices, professional competencies, and cultural expectations. Historical transition research demonstrates that widespread diffusion involves adjustments across multiple dimensions of society, meaning that technically superior innovations may fail to transform established systems when complementary institutional and social conditions are absent (Kanger et al., 2019). This is particularly relevant to renewable energy because solar, wind, storage, distributed generation, and related technologies require supporting grids, financing systems, maintenance capacities, regulatory arrangements, markets, technical skills, and social acceptance. The availability of renewable resources or individual technologies is therefore only one component of transition capacity.

Related research on Technological Innovation Systems (TIS) further demonstrates the importance of knowledge production, entrepreneurial experimentation, market formation, resource mobilization, legitimacy, network development, and institutional support for the successful development and diffusion of emerging technologies. Recent reviews suggest that TIS analysis and sustainability-transition research have increasingly converged because both seek to explain why promising technologies advance in some settings while remaining marginal in others. In particular, stable policy support, learning networks, university–industry interaction, knowledge exchange, and the accumulation of technological capabilities are essential for transforming technological potential into sustained innovation and diffusion (Weckowska et al., 2025). Comparative assessments of transition frameworks likewise indicate that the MLP, TIS, and transition-governance perspectives illuminate different but complementary dimensions of systemic change; integrating insights concerning cross-level interactions, innovation-system functions, and governance processes can therefore improve the analysis of complex sustainability transitions (Bakhuis et al., 2024).

These theoretical considerations are highly relevant to Iran, whose energy transition unfolds within a distinctive combination of abundant fossil resources, substantial renewable-energy potential, established fossil-fuel infrastructures, economic constraints, and institutional challenges. Iran possesses considerable geographical potential for solar and wind energy development, particularly because of high levels of solar irradiation across large areas of the country and favorable wind conditions in several regions. Strategic assessments have consequently identified renewable energy as an important opportunity for diversifying the national energy portfolio, improving environmental performance, and strengthening the long-term resilience of the energy system. Research focusing on solar energy in Iran has highlighted natural resource availability and domestic scientific and technical capacities as important strengths while simultaneously identifying investment limitations, policy weaknesses, and institutional barriers as factors preventing the full exploitation of this potential (Heydari, 2022).

Broader strategic analyses have reached similar conclusions. Iran possesses scientific and technical capabilities, research institutions, knowledge-based enterprises, and opportunities for domestic technological development that could provide a foundation for renewable-energy expansion. However, the development of these capabilities is conditioned by the quality of the policy environment, access to finance, coordination among relevant institutions, technological supply chains, and the ability to convert research and development activities into commercially viable applications. Strategic assessments of renewable-energy development in Iran have therefore emphasized both the substantial opportunities associated with indigenous technological development and the persistent weaknesses that constrain implementation and diffusion (Ordu et al., 2021). The coexistence of strong natural and technological opportunities with persistent structural barriers indicates that Iran's renewable-energy challenge cannot be adequately understood as a problem of resource availability alone.

Technological dependence constitutes another important dimension of this challenge. The expansion of renewable-energy industries requires access to specialized equipment, technical knowledge, testing facilities, manufacturing capacities, maintenance services, and integrated supply chains. Previous research on renewable-energy development in Iran has identified dependence on external technologies and inadequate localization of key technological capabilities as significant obstacles to the development of a competitive domestic renewable-energy sector (Mousavi Darcheh et al., 2018). These constraints become especially significant when international restrictions, exchange-rate instability, and difficulties in technology transfer increase the costs and risks associated with importing advanced technologies. Consequently, strengthening domestic technological learning and innovation capacity is closely connected to broader institutional, financial, and industrial-development policies.

Economic and geopolitical conditions further complicate the transition process. Renewable-energy projects are generally capital intensive, making investment conditions, financing costs, exchange-rate stability, risk perceptions, and access to domestic and international financial resources particularly important. Studies of the Iranian context have identified economic sanctions, technology-transfer restrictions, financial limitations, and macroeconomic instability as important barriers to renewable-energy development while also highlighting research support, technological development, and greater private-sector involvement as potential transition drivers (Salimi et al., 2023). These factors demonstrate how pressures that originate at the broader landscape level can influence both regime stability and niche development. International restrictions may constrain access to finance and technologies, while global decarbonization trends and advances in renewable-energy technologies simultaneously create incentives for the energy system to diversify.

The persistence of barriers is particularly evident when specific renewable-energy innovation systems are examined. Research on Iran's wind turbine sector has shown that transition difficulties are associated not merely with the characteristics of wind technology itself but with weaknesses in innovation-system performance, inconsistent policy support, limited technological capabilities, and shortcomings in coordination among relevant actors (Rahmani et al., 2022). Such findings reinforce the importance of moving beyond technology-specific assessments toward analyses that consider interactions among policy, institutions, markets, technological capabilities, and broader structural pressures. A technology may possess considerable theoretical potential yet remain unable to diffuse if the surrounding socio-technical system does not provide appropriate financing mechanisms, institutional support, infrastructure, market demand, and opportunities for learning and commercialization.

Institutional structures are particularly important in the Iranian case because the existing energy system has developed around the production and consumption of fossil fuels. Institutional arrangements, organizational interests, energy governance structures, and economic incentives can reinforce existing technological trajectories and reduce the capacity of alternative technologies to compete. A socio-technical analysis of institutional barriers in Iran indicates that the characteristics of the fossil-fuel-based economy, political-economic structures, interactions among institutions and organizations, and weaknesses in institutional arrangements have substantially constrained the effectiveness of energy-transition efforts (Aghlimoghadam, 2025). From an MLP perspective, these conditions can be understood as dimensions of regime lock-in: established rules, incentives, infrastructures, and actor relationships reproduce the incumbent system even when landscape pressures increasingly favor transition.

The Iranian case therefore illustrates a central proposition of sustainability-transition theory: strong landscape pressure and promising niche innovations do not automatically generate regime transformation. Climate concerns, global decarbonization, technological progress, energy-security considerations, and changing international energy markets may create substantial momentum for renewable energy, but the translation of this momentum into systemic change depends on the capacity of the existing regime to adapt and on the ability of emerging niches to accumulate sufficient technical, organizational, financial, and institutional strength. Transition research consequently calls for greater attention to the interactions among policy, governance, agency, business strategies, innovation processes, social dynamics, and institutional change rather than treating these factors independently (Köhler et al., 2019). In this sense, the crucial analytical question is not simply whether Iran has drivers or barriers to renewable-energy development, but how these factors are distributed across different levels of the socio-technical system and how their interactions shape the direction and pace of transformation.

Despite the value of previous studies, the Iranian renewable-energy literature remains comparatively fragmented in its analytical focus. SWOT-based studies have identified strengths, weaknesses, opportunities, and threats associated with renewable-energy development (Heydari, 2022; Ordu et al., 2021; Salimi et al., 2023); technology-oriented research has documented problems of technological dependence and localization (Mousavi Darcheh et al., 2018); innovation-system studies have examined transition failures in specific sectors such as wind energy (Rahmani et al., 2022); and recent socio-technical research has drawn attention to institutional barriers and fossil-fuel-based structures (Aghlimoghadam, 2025). Although these studies provide important insights, examining individual technologies, strategic factors, or institutional dimensions separately may obscure the cross-level relationships through which transition dynamics actually emerge.

This limitation is important because sustainability transitions are inherently systemic. The conceptual foundations of transition studies emphasize interactions among technological innovations, markets, infrastructures, social practices, institutions, and political processes (Markard et al., 2012), while the MLP specifically directs attention to the alignment or misalignment of landscape pressures, regime structures, and niche developments (Geels, 2017). Policy analysis further shows that interventions can have different effects depending on whether they protect emerging niches, alter regime incentives, or respond to landscape-level developments (Kern, 2012). Accordingly, a comprehensive analysis of Iran's renewable-energy transition requires the simultaneous identification of enabling and constraining factors across multiple analytical levels rather than a simple inventory of isolated technical, economic, or policy problems.

An integrated MLP-based analysis can also clarify why individual factors may perform different roles depending on their position and interaction with other elements of the system. Natural solar and wind potential, for example, represents an important technological and environmental opportunity, but its contribution to transition depends on grid capacity, financing, market arrangements, policy continuity, investment conditions, and technological capabilities. Similarly, research and development may create promising niche innovations, yet those innovations may remain marginal in the absence of commercialization mechanisms, supportive regulations, learning networks, or access to capital. Conversely, landscape pressures such as climate change, energy-security concerns, or international decarbonization can destabilize established expectations without producing meaningful transformation when regime-level institutional and economic lock-ins remain sufficiently strong. This relational interpretation reflects the core logic of transition pathways, according to which the outcomes of systemic change depend on the timing, strength, and alignment of developments occurring at different levels (Geels & Schot, 2007).

Moreover, examining renewable-energy transition through sustainability dimensions can enrich the MLP analysis by demonstrating that drivers and barriers are rarely confined to a single domain. Financing constraints may simultaneously have economic, technological, and institutional consequences; technological dependence may affect industrial development, investment, and national energy resilience; subsidy structures may shape market competitiveness, consumption behavior, and environmental outcomes; and innovation ecosystems may connect technical learning with employment, entrepreneurship, industrial policy, and private-sector participation. Such multidimensionality reinforces recent arguments for complementary transition frameworks capable of connecting socio-technical change with innovation-system functions and governance mechanisms (Bakhuis et al., 2024). It also supports the broader understanding that achieving a net-zero or substantially decarbonized energy system requires coordinated changes across technologies, institutions, markets, infrastructures, and sectors rather than isolated interventions (Markard & Rosenbloom, 2023).

Accordingly, there is a need for a comprehensive and context-sensitive analysis capable of organizing the dispersed factors identified in previous research into a coherent socio-technical structure. Applying the MLP to Iran can reveal how macro-level pressures create both opportunities and constraints, how characteristics of the incumbent energy regime facilitate or resist change, and how niche-level technological and innovation capacities may develop into viable alternatives. Such an approach can also provide a stronger analytical basis for understanding where transition bottlenecks are concentrated and why considerable renewable-resource potential has not necessarily translated into proportionate systemic transformation. By treating transition as an interactive and co-evolutionary process, the MLP provides a framework for connecting external pressures, structural lock-ins, institutional capabilities, technological learning, innovation ecosystems, and emerging alternatives within a single analytical perspective.

Therefore, this study aims to identify, classify, and analyze the key drivers and barriers shaping the sustainable transition to renewable energy in Iran across the landscape, regime, and niche levels of the Multi-Level Perspective.

2. Methods and Materials

The present study aims to identify, classify, and analyze the key drivers and barriers influencing the transition toward renewable energy in Iran. Given the exploratory nature of the research and the need to achieve a comprehensive understanding of the factors affecting the energy transition, a qualitative approach based on a literature review and content analysis is employed. In this regard, the study seeks to consolidate and integrate existing knowledge on the energy transition to provide a comprehensive understanding of the forces that facilitate and constrain renewable energy development in Iran. For this purpose, relevant studies, technical reports, and policy documents were initially collected and reviewed. Subsequently, the extracted factors were organized, categorized, and analyzed within the MLP framework.

Table 1

Literature Review Summary.

No.	Study	Main focus	Key findings
1	Geels (2002)	Explaining technological transitions	Transitions involve simultaneous changes in technologies, institutions, markets, and user behaviors.
2	Geels & Schot (2007)	Transition pathways	Introduced four major transition pathways.
3	Verbong & Geels (2007)	Dutch electricity transition	Highlighted the role of rules, networks, and technologies in shaping energy transitions.
4	Smith et al. (2010)	Critique of MLP	Emphasized challenges related to MLP operationalization and the need for greater attention to power, policy, and agency.
5	Kern (2012)	Innovation policy assessment	Demonstrated the applicability of MLP for evaluating innovation policies and transition strategies.
6	Markard et al. (2012)	Sustainability transitions field	Introduced sustainability transitions as an emerging interdisciplinary research field.
7	Köhler et al. (2019)	Transition research agenda	Highlighted the importance of governance, policy, actors, and methodological approaches in transition studies.
8	Geels (2020)	Micro-foundations of MLP	Emphasized the importance of actor agency, learning processes, and institutional dynamics.
9	Rahmani et al. (2022)	Iranian wind turbine industry	Identified transition failures in Iran’s wind energy sector due to weak innovation systems and policy limitations.
10	Aghlimoghadam (2025)	Energy transition in Iran	Demonstrated that institutional weaknesses and fossil fuel-based economic structures hinder effective energy transition.

2.1. Inclusion and Exclusion Criteria for Studies

To ensure the quality and relevance of the selected studies in relation to the research objectives, a set of inclusion and exclusion criteria was established. The inclusion criteria consisted of: (1) direct relevance to energy transition or renewable energy development, (2) providing evidence or analysis regarding factors influencing energy transition, (3) publication in reputable scientific journals, specialized technical reports, or official policy documents, and (4) containing sufficient analytical content. Furthermore, studies addressing institutional, economic, social, technological, or environmental dimensions of energy transition were included in the analytical process. Conversely, studies that focused exclusively on the technical design aspects of energy equipment, lacked direct relevance to energy transition processes, did not provide sufficient analytical information, or represented duplicated findings from other studies, were excluded from the review process. Applying these criteria ensured that the final set of selected studies demonstrated the strongest possible alignment with the research objectives.

2.2. Screening Process and Source Selection

Following the search and collection of relevant sources, the screening process was conducted in several stages. First, duplicate records were removed. Subsequently, the titles and abstracts of the studies were examined to assess their relevance to the research topic. Finally, the full texts of potentially relevant studies were evaluated based on the predefined inclusion and exclusion criteria. Only studies that provided meaningful insights into the factors influencing the transition toward renewable energy were selected for the final analysis. After selecting the sources, the data extraction process was initiated. Relevant concepts, barriers, opportunities, policies, trends, and capacities reported in the reviewed studies were extracted and recorded. The collected data were then coded using qualitative content analysis. In this process, initial open codes were first identified, similar codes were subsequently merged, and the resulting concepts were organized into subcategories and main categories. This analytical process was conducted iteratively, integrating empirical data and theoretical concepts to minimize overlap among categories and to develop a coherent set of key factors influencing the renewable energy transition. The extracted factors were subsequently used as the foundation for further analyses within the research framework.

2.3. Classification of Findings Based on the MLP Framework

In the final stage of the analysis, the identified factors were classified into three levels of landscape, regime, and niche based on Geels' MLP framework. This framework enables the simultaneous analysis of macro-level trends, institutional structures, and innovative capacities, and is therefore considered one of the most comprehensive approaches for examining socio-technical transitions.

In addition to classification across the three MLP levels, each factor was also identified based on its role in the transition process as either a "driver" or a "barrier." This approach enabled a systematic analysis of the relationships among factors and facilitated an explanation of the mechanisms that strengthen or hinder the transition to renewable energy in Iran.

3. Findings and Results

Following the literature review and qualitative content analysis, the factors influencing the renewable energy transition in Iran were extracted, coded, and categorized within the MLP framework. The analysis identified 58 factors, organized into three analytical levels: landscape, regime, and niche. In addition to their position within the MLP framework, each factor was classified by its proposed role in the transition process as a driver, barrier, dual-role factor, or conditional driver. The factors were further classified according to sustainability dimensions, including economic, environmental, social, technological, and institutional-policy aspects.

The findings demonstrate that the renewable energy transition in Iran is shaped by the dynamic interaction among macro-level pressures, established energy system structures, and emerging innovation capacities. While landscape-level factors represent external pressures and opportunities for transformation, regime-level factors reflect the structural conditions that either facilitate or constrain transition processes. Meanwhile, niche-level factors indicate the technological and innovative capabilities that can support the emergence of alternative energy pathways. The following sections present detailed findings for each MLP level and discuss the roles of the identified drivers and barriers in shaping the transition dynamics of Iran's renewable energy system. Accordingly, the following subsections present the findings in three parts: landscape-level, regime-level, and niche-level factors.

3.1. Landscape-Level Factors

The landscape level represents macro-level trends, structural pressures, and long-term transformations that are beyond the direct control of energy system actors but can significantly influence the overall direction of energy transition. The findings of this study indicate that a considerable proportion of the factors affecting energy transition in Iran are located at this level. These factors are mainly characterized by economic, political, environmental, and social dimensions and provide the broader context in which opportunities and constraints for renewable energy transition emerge.

The findings presented in Table 2 demonstrate that landscape-level factors represent the broad external pressures, long-term trends, and macro-level developments that influence the direction and pace of renewable energy transition in Iran. According to the MLP framework, landscape factors are generally beyond the direct control of energy system actors; however, they create external pressures that can destabilize existing regimes and open windows of opportunity for alternative energy pathways.

The identified factors at this level were categorized into environmental, economic, technological, geopolitical, social, and institutional-policy dimensions, indicating the multidimensional nature of landscape pressures affecting Iran's energy transition. Among the identified landscape-level factors, climate change and environmental pressures emerged as one of the most influential drivers of the renewable energy transition. Increasing GHG emissions, global temperature rise, water stress, and growing environmental risks have strengthened international and domestic pressures to reduce carbon emissions and diversify energy systems. In Iran, where the energy sector remains highly dependent on fossil fuels, environmental challenges and climate-related vulnerabilities have heightened the need to shift toward cleaner energy sources. Therefore, climate change is a landscape-level pressure that challenges the long-term sustainability of fossil-fuel-based energy systems and enhances the legitimacy of renewable energy alternatives.

Another important category of landscape-level drivers relates to international climate commitments, global decarbonization trends, and clean energy market developments. International agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement, and global carbon-reduction initiatives have created normative and institutional pressures on countries to adopt low-carbon development pathways. In parallel, rapid technological advancements, declining costs of renewable energy technologies, and the expansion of global clean energy markets have increased the feasibility and attractiveness of renewable energy investments. These trends create technological and economic opportunities for Iran to participate in emerging renewable energy markets, provided that appropriate institutional and financial conditions are established.

Table 2

Factors Influencing Renewable Energy Transition at the Landscape Level.

No.	Main theme	Sources	Factor	Sustainability dimension	Proposed role
1	Climate change and environmental pressures	IPCC, 2023; WHO, 2022; UNFCCC, 1992	Intensification of climate change, global warming, and increasing climate-related risks	Environmental + social	Driver
2			Increasing GHG emissions and the necessity of carbon reduction	Environmental + institutional-policy	Driver
3	Air pollution and public health	IPCC, 2023; WHO, 2022; Ordu et al., 2021	Increasing public health and environmental consequences resulting from air pollution and the consumption of polluting fuels	Environmental + social	Driver
4	International climate commitments and pressures	UNFCCC, 1992; Paris Agreement, 2015; International Renewable Energy Agency IRENA, 2024; Salimi et al., 2023; Heydari, 2022	International climate regimes, agreements, and commitments for reducing carbon emissions, including UNFCCC, the Paris Agreement, and COP initiatives	Institutional-policy + environmental	Driver
5			Global pressure for renewable energy expansion and decarbonization	Institutional-policy + environmental	Driver
6	Global decarbonization trends	IEA, 2024; IRENA, 2024; REN21, 2024	Global movement toward low-carbon economies, sustainable energy systems, and reduced dependence on fossil fuels	Economic + environmental	Driver
7	Global clean energy technology and market trends	IEA, 2024; IRENA, 2024; REN21, 2024	Global expansion of renewable energy technologies, investments, and clean energy markets	Technical + economic	Driver
8	Energy efficiency	IEA, 2024; IRENA, 2024; Iranian Parliament Research Center, 2025; SATBA, 2025	Improvement of energy efficiency and optimization of energy consumption at the global level	Technical + economic	Driver
9	Global energy security	IEA, 2024; IRENA, 2024; SATBA, 2025; Ministry of Energy, 2026	Increasing global concerns regarding energy security, resilience, and sustainability of energy supply	Economic + institutional-policy	Driver
10			Necessity of diversifying energy portfolios and reducing the vulnerability of energy systems to supply crises	Economic + institutional-policy	Driver

11	Fossil fuel Resource constraints	IEA, 2024; IRENA, 2024; REN21, 2024	Limitations, depletion risks, and vulnerability of fossil fuel resources for sustainable energy supply	Economic + environmental	Driver
12	Macroeconomic pressures	IEA, 2024; Geels, 2007; Seventh National Development Plan, 2023	Economic instability, inflation, and exchange rate fluctuations as macro-level pressures affecting energy investments	Economic	Barrier
13	International constraints	IEA, 2024; Geels, 2007; Seventh National Development Plan, 2023; Salimi et al., 2023	Economic sanctions, banking restrictions, limitations on foreign investment, and technology transfer constraints	Economic + institutional-policy + technical	Barrier
14	Cost and risk of renewable energy development	IEA, 2024; Geels, 2007; Vice Presidency for Science, Technology and Knowledge-Based Economy, 2025	Increasing costs and investment risks, and reduced attractiveness of renewable energy investments due to sanctions and economic fluctuations	Economic + technical	Barrier
15	Geopolitical developments	IEA, 2024; IRENA, 2024; Ministry of Energy, 2026	Wars, regional tensions, threats to infrastructure security, and disruptions in energy supply routes	Institutional-policy + economic + technical	Barrier
16	Geopolitical changes in energy markets	IEA, 2024; IRENA, 2024; Ministry of Energy, 2026	Changes in global energy market structures and regional competition in the energy sector	Economic + institutional-policy	Dual Role
17	Iran’s natural and geographical capacities	IRENA, 2024; REN21, 2024; Heydari, 2022; Salimi et al., 2023	Significant natural and geographical potential of Iran for solar and wind energy development	Technical + environmental	Conditional driver
18	Public awareness, social developments, and social demands	IPCC, 2023; WHO, 2022; United Nations, 2015	Increasing social sensitivity toward air pollution, public health, and clean energy	Social + environmental	Driver
19			Increasing public awareness and social demands for renewable energy development	Social + institutional-policy	Driver
20	Emerging social discourses	United Nations, 2015; IPCC, 2023; Ministry of Energy, 2026	Expansion of sustainability, resilience, and energy security discourses	Social + institutional-policy	Driver

The findings also highlight energy security concerns and fossil fuel resource constraints as important drivers of the transition. Increasing uncertainty in global energy markets, geopolitical risks, and the need to ensure a reliable energy supply have encouraged countries to diversify their energy portfolios. For Iran, despite its significant fossil fuel reserves, challenges such as rising domestic consumption, electricity and gas supply imbalances, and vulnerability to external market fluctuations underscore the importance of renewable energy development as a strategy to enhance energy resilience and security.

However, not all landscape-level factors facilitate transition. The results indicate that macroeconomic pressures, international constraints, and geopolitical uncertainties represent significant external barriers. Economic instability, inflation, exchange rate fluctuations, international sanctions, banking restrictions, and limitations on technology transfer reduce investment attractiveness and increase the cost of renewable energy projects. These factors weaken Iran’s energy system’s ability to access advanced technologies, attract foreign investment, and develop international cooperation networks. Consequently, although the renewable energy transition is supported by global trends, economic and geopolitical pressures may slow down the realization of transition pathways.

Furthermore, Iran’s natural and geographical capacities represent a conditional driver rather than an automatic advantage. The country’s high solar radiation potential, suitable wind corridors, and extensive geographical diversity provide significant opportunities for renewable energy expansion. Nevertheless, transforming these natural advantages into actual transition outcomes requires supportive policies, investment mechanisms, technological capabilities, and effective governance structures. Therefore, resource availability alone cannot guarantee a successful transition without complementary institutional and technological capacities.

Finally, social awareness, public demand, and emerging sustainability discourses were identified as important social drivers at the landscape level. Increasing public sensitivity toward air pollution, environmental degradation, energy security, and sustainable development can strengthen social acceptance of renewable energy policies. These social dynamics help create broader legitimacy for the energy transition and encourage policymakers to adopt more sustainable energy strategies.

Overall, the landscape-level analysis indicates that the renewable energy transition in Iran is influenced by a combination of enabling pressures and constraining conditions. While climate change, global decarbonization, technological progress, energy security concerns, and social sustainability discourses create strong momentum for the transition, economic instability, sanctions, and geopolitical uncertainties limit the energy system's ability to respond effectively. Therefore, the transformation of landscape pressures into actual transition outcomes depends largely on regime-level reforms and the strengthening of innovation capacities at the niche level.

3.2. Regime-Level Factors

The socio-technical regime encompasses the established structures of the energy system, comprising interconnected elements such as regulations, institutions, infrastructure, dominant technologies, managerial practices, consumption patterns, and market mechanisms. The findings of this study indicate that the largest number of identified factors is concentrated at the regime level, highlighting the decisive role of institutional structures and energy governance arrangements in shaping Iran's energy transition process.

The findings presented in Table 3 indicate that the regime level is the most influential and challenging layer in Iran's renewable energy transition. According to the MLP framework, the socio-technical regime includes established technologies, institutions, regulations, infrastructures, market structures, user practices, and governance arrangements that maintain the stability of the existing energy system. Therefore, changes at this level are generally more difficult to achieve because they are associated with strong institutional, economic, and technological lock-ins.

The results demonstrate that fossil fuel dependency and existing consumption patterns constitute one of the most significant structural barriers within Iran's energy regime. The dominance of fossil fuels in electricity generation, transportation, and industrial activities has created a path-dependent energy system in which existing infrastructures, investment patterns, and consumption behaviors reinforce continued reliance on conventional energy sources. Furthermore, high energy intensity and low energy-use efficiency increase economic and environmental pressures, limiting the competitiveness of renewable energy alternatives.

Another major category of regime-level barriers concerns energy subsidies, pricing mechanisms, and electricity market structures. The findings show that non-market-based energy pricing and extensive fossil fuel subsidies reduce the economic attractiveness of renewable energy projects by weakening their competitiveness compared with conventional energy sources. The absence of a fully competitive electricity market, weak price discovery mechanisms, and limited financial incentives for renewable electricity development prevent renewable technologies from achieving large-scale diffusion within the existing energy system.

Table 3

Factors Influencing Renewable Energy Transition at the Regime Level.

No.	Main Theme	Sources	Factor	Sustainability Dimension	Proposed Role
1	Consumption patterns and fossil fuel dependency	IEA, 2024; IRENA, 2024; Ministry of Energy, 2026; Salimi et al., 2022	Structural dependence of the energy production and consumption system on fossil fuels	Economic + technical + social	Barrier
2			High energy intensity and low energy consumption efficiency in Iran	Economic + environmental	Barrier
3	Public awareness and social acceptance	IEA, 2024; Geels, 2017; Ministry of Energy, 2026	Limited public and managerial awareness regarding the benefits of renewable energy	Social	Barrier
4	Energy subsidies, pricing, and electricity market	IEA, 2024; IMF, 2023; Ministry of Energy, 2026; SATBA, 2025	Non-market-based energy pricing and fossil fuel subsidies as barriers to renewable energy competitiveness	Economic + institutional-policy	Barrier
5			Lack of a truly competitive market for renewable electricity and weak clean electricity pricing mechanisms	Economic + institutional-policy	Barrier
6	Investment and financing	IEA, 2024; IRENA, 2024; Iranian Parliament Research Center, 2025; SATBA, 2025; Seventh National Development Plan, 2023	Limited access to financing and investment resources for renewable energy projects	Economic	Barrier
7			Increased investment and equipment costs due to sanctions and exchange rate fluctuations	Economic + technical	Barrier

8			Weak guaranteed purchase mechanisms, low renewable electricity tariffs, and long investment payback periods	Economic + institutional-policy	Barrier
9			High investment risks and limited private sector participation in renewable energy development	Economic + institutional-policy	Barrier
10	Electricity generation system conditions	IEA, 2024; IRENA, 2024; Ministry of Energy, 2026; SATBA, 2025	Electricity and natural gas supply-demand imbalances, aging thermal power plants, and the necessity of diversifying electricity supply sources	Technical + economic	Dual Role / Transition Driver
11	Grid infrastructure and site selection	Geels, 2017; Geels & Schot, 2007; SATBA, 2025; Ministry of Energy, 2026	Weak national grid capacity for connecting and absorbing renewable energy generation	Technical + institutional-policy	Barrier
12			Challenges related to land availability, site selection, and grid connection of large-scale renewable projects	Technical + institutional-policy	Barrier
13	Distributed generation and decentralized electricity	IEA, 2024; IRENA, 2024; SATBA, 2025; Ministry of Energy, 2026	Potential for expanding distributed generation, rooftop solar systems, and decentralized energy networks	Technical + social	Driver
14	Institutional capacity and governance	Geels, 2017; Geels & Schot, 2007; SATBA, 2025; Ministry of Energy, 2026	Development of institutional capacity and participation of public and private actors in renewable energy expansion	Institutional-policy + economic	Driver
15			Weak institutional coordination, bureaucracy, lengthy contractual processes, and instability of implementation support	Institutional-policy	Barrier
16	Policy documents, regulations, and policy instruments	IEA, 2024; IRENA, 2024; WHO, 2022; Seventh National Development Plan, 2023; Iranian Parliament Research Center, 2025; SATBA, 2025; Ministry of Energy, 2026	Existence of supportive objectives, regulations, and policy documents for renewable energy development, including the Seventh Development Plan, Knowledge-Based Production Leap Law, and Energy Consumption Reform Law	Institutional-policy	Driver
17			Development of guaranteed electricity purchase mechanisms, green electricity markets, and renewable electricity export policies	Economic + institutional-policy	Driver
18			Tax, customs, and consumption incentives for renewable energy development	Economic + institutional-policy	Driver
19			Pollution control regulations and gradual energy carrier price reform policies	Environmental + economic + institutional-policy	Driver
20			Challenges in the effective implementation of supportive regulations and policies, including Article 12 of the Production Improvement and Competitiveness Barriers Removal Law	Institutional-policy	Barrier
21			Absence of an integrated, binding, and coordinated roadmap for renewable energy development	Institutional-policy	Barrier
22	Sectoral applications of solar energy	Seventh National Development Plan, 2023; Iranian Parliament Research Center, 2025; SATBA, 2025; Ministry of Energy, 2026	Development of solar parks and expansion of solar power plants in schools, industries, agricultural sectors, and public buildings	Technical + social + institutional-policy	Driver

The analysis also highlights investment and financing limitations as critical regime-level constraints. Limited access to financial resources, high capital costs, exchange rate fluctuations, and uncertainty about investment returns have reduced private-sector participation in renewable energy projects. In addition, weak guaranteed purchase mechanisms, insufficient renewable electricity tariffs, and lengthy payback periods have increased investment risks and constrained the expansion of renewable energy infrastructure. These findings indicate that financial mechanisms and market arrangements play a central role in determining the extent to which renewable technologies can move from niche spaces toward mainstream adoption.

Infrastructure-related factors, particularly grid limitations and challenges associated with site selection and connection of renewable energy projects, represent another important barrier at the regime level. Although Iran has significant renewable energy potential, insufficient grid flexibility, limited transmission capacity, and challenges in integrating intermittent renewable generation restrict the large-scale deployment of solar and wind technologies. Therefore, infrastructure modernization and smart grid development are necessary conditions for transforming renewable energy potential into actual system-level outcomes. Despite these barriers, the findings also identify several regime-level drivers that can facilitate energy transition. The development of institutional capacity, participation of public and private actors, supportive policy instruments, renewable electricity purchase mechanisms, green electricity markets, and sectoral solar energy applications represent important enabling factors. Recent policy initiatives, including renewable energy development programs, supportive regulations, and mechanisms to attract private investment, can create favorable conditions to accelerate the diffusion of renewable energy.

However, the effectiveness of these supportive measures depends largely on implementation capacity and policy stability. The findings reveal that weak institutional coordination, bureaucratic processes, inconsistent regulatory implementation, and the absence of an integrated, binding renewable energy roadmap remain significant obstacles. These challenges indicate that policy formulation alone is insufficient; rather, effective governance mechanisms and institutional coordination are required to translate policies into practical transition outcomes.

Overall, the regime-level analysis demonstrates that structural characteristics of the existing energy system primarily constrain the renewable energy transition in Iran. While technological potential and supportive policies create opportunities for transition, overcoming fossil fuel lock-in requires fundamental reforms in energy pricing, financing mechanisms, market structures, infrastructure development, and governance arrangements. Therefore, transformation at the regime level represents a critical prerequisite for enabling niche innovations to expand and contribute to a broader sustainable energy transition.

3.3. Niche-Level Factors

The niche level refers to protected, innovative spaces where new technologies, ideas, and alternative models are developed, tested, and prepared for integration into the dominant socio-technical regime. Within the MLP framework, niches provide the conditions required for the emergence and maturation of transformative innovations that can potentially challenge and reshape existing energy structures.

Table 4 shows factors influencing the renewable energy transition at the niche level, where a significant portion of transition capacity is concentrated. These capacities mainly include renewable energy technologies, research and development activities, knowledge-based companies, pilot projects, scientific institutions, and emerging innovation networks. Although niche-level innovations possess substantial potential to accelerate the renewable energy transition, their successful diffusion into the dominant energy regime depends on supportive institutional arrangements, sustainable financing mechanisms, technological infrastructure, and effective policy frameworks. Therefore, strengthening niche capacities and creating stronger connections between innovation actors and the existing energy regime are essential conditions for advancing renewable energy development in Iran.

Technological limitations and insufficient specialized capabilities are among the most important barriers to the renewable energy transition at the niche level. Dependence on foreign technologies, weak supply chains, limited capacity to localize key technologies, insufficient specialized infrastructure, and the impacts of international sanctions on technology transfer constitute major constraints on the development of this sector.

Furthermore, the lack of testing and standardization facilities, inadequate maintenance and technical support services, and shortages of specialized human resources have challenged the development, diffusion, and competitiveness of renewable energy technologies in Iran. These limitations restrict niche-level innovations from maturing and effectively penetrating the dominant energy regime.

Table 4

Factors Influencing Renewable Energy Transition at the Niche Level.

No.	Main Theme	Sources	Factor	Sustainability Dimension	Proposed Role
1	Technological gaps and constraints	IEA, 2024; IRENA, 2024; Mousavi Darcheh et al., 2018; Salimi et al., 2023	Gaps in technical knowledge and specialized skills for designing, manufacturing, operating, and evaluating renewable energy projects	Technical + social	Barrier
2			Weak infrastructure for testing, standardization, equipment quality assessment, and maintenance services	Technical + institutional-policy	Barrier

3			Technological gap with leading countries and limited access to advanced technologies due to international sanctions	Technical + economic	Barrier
4			Weak supply chains, limited domestic production of equipment, and a restricted number of active companies in the renewable energy sector	Technical + economic	Barrier
5			Dependence of renewable energy technology performance on climatic and geographical conditions, and the need to develop energy storage and generation fluctuation management systems	Technical	Barrier
6	Scientific capacity, research and development, and technological learning	Geels, 2007; IRENA, 2024; Vice Presidency for Science, Technology and Knowledge-Based Economy, 2025; Salimi et al., 2023	Scientific, academic, and human capital capacities for learning, localization, and development of renewable energy technologies	Technical + social	Driver
7			Development of advanced knowledge and technologies in solar, wind, and energy storage systems	Technical + environmental	Driver
8			Expansion of scientific collaborations, specialized forums, international networks, and knowledge transfer in clean energy technologies	Technical + institutional-policy + social	Driver
9	Innovation ecosystem and commercialization	OECD, 2023; Geels, 2007; IRENA, 2024; Vice Presidency for Science, Technology and Knowledge-Based Economy, 2025	Formation of innovation ecosystems, knowledge-based companies, and clean energy startups	Technical + economic	Driver
10			Collaboration among universities, research institutions, industries, and the private sector in renewable energy technology development	Technical + social + economic	Driver
11			Development of innovation ecosystems and commercialization of clean energy technologies	Economic + technical	Driver
12	Pilot projects and experimental production	IEA, 2024; IRENA, 2024; SATBA, 2025; Ministry of Energy, 2026	Implementation of pilot projects for testing emerging technologies and new business models	Technical + economic	Driver
13			Development of experimental and industrial production capacities for renewable energy equipment, particularly photovoltaic panels	Technical + economic	Driver
14	Innovation financing and technology development	IEA, 2024; IRENA, 2024; OECD, 2023; Vice Presidency for Science, Technology and Knowledge-Based Economy, 2025	Lack of sustainable financial resources for research and development, and technology-oriented studies	Economic + technical	Barrier
15			Limited foreign investment and sensitivity of technology costs to exchange rate fluctuations	Economic	Barrier
16			Weak financing mechanisms for high-risk projects, pilot initiatives, and commercialization of renewable energy technologies	Economic + technical	Barrier

In contrast, research and development capacities represent the most significant niche-level drivers of renewable energy transition. The activities of universities, research institutions, knowledge-based companies, startups, and pilot projects, along with the availability of specialized human capital and supportive programs, have created considerable potential for technology localization and innovation development. However, limited financial resources, budget constraints, difficulties in accessing foreign capital, and exchange rate fluctuations have slowed down technology development and the commercialization of renewable energy innovations. Therefore, strengthening technological infrastructure, supporting research and development activities, enhancing human capital, and establishing sustainable financing mechanisms are among the most important requirements for accelerating the transition to renewable energy in Iran.

3.4. Interactions between Landscape, Regime, and Niche Levels

The MLP emphasizes that sustainability transitions do not occur as a result of changes within a single level; rather, they emerge from the dynamic interactions among landscape pressures, regime structures, and niche innovations. Therefore, identifying the factors at each level is insufficient without analyzing how these levels influence and reshape one another during the transition process. In the context of Iran's renewable energy transition, the interaction among the three MLP levels reveals a complex transformation pathway. At the landscape level, external pressures such as climate change, global decarbonization trends, energy security concerns, geopolitical uncertainties, and international environmental commitments create pressures on the existing fossil fuel-based energy regime. These pressures gradually challenge the legitimacy, economic efficiency, and long-term sustainability of the dominant energy system.

However, landscape pressures alone cannot guarantee a successful transition. Their transformative effects depend largely on the flexibility and responsiveness of the regime level. In Iran, the existing energy regime is characterized by strong dependence on fossil fuels, subsidized energy prices, centralized governance structures, limited investment mechanisms, and fossil-based infrastructures. These characteristics create institutional and technological lock-ins that slow down the diffusion of renewable energy technologies. Therefore, structural reforms in energy policies, market mechanisms, financing systems, and governance arrangements are required to enable landscape pressures to translate into actual transition processes.

At the same time, the niche level provides the technological and innovative alternatives necessary to replace or transform the dominant regime. Renewable energy technologies, research and development activities, knowledge-based companies, pilot projects, and university–industry collaborations represent emerging innovation spaces that can challenge the existing energy configuration. However, the expansion of niche innovations depends on supportive regime conditions, including stable policies, financial mechanisms, infrastructure development, and institutional coordination. The interaction among these three levels suggests that the renewable energy transition in Iran follows a co-evolutionary process. Landscape pressures create windows of opportunity, regime reforms determine the energy system's capacity to respond, and niche innovations provide the technological and organizational alternatives required for transformation. Therefore, accelerating the renewable energy transition requires simultaneous actions across all three levels rather than focusing exclusively on technological development or policy interventions.

4. Discussion and Conclusion

The present study sought to identify and analyze the principal drivers and barriers shaping the sustainable transition toward renewable energy in Iran through the Multi-Level Perspective (MLP). The findings revealed that Iran’s renewable energy transition is a complex socio-technical process resulting from interactions among landscape pressures, regime structures, and niche innovations rather than from technological development alone. Overall, 58 influential factors were identified, including 20 factors at the landscape level, 22 at the regime level, and 16 at the niche level. The distribution of the identified factors showed that landscape-level conditions predominantly generate pressures and opportunities for transition, regime-level factors contain the greatest concentration of structural barriers, and niche-level factors provide important technological and innovative capacities while simultaneously suffering from financial and technological limitations. This pattern supports the central proposition of sustainability-transition research that systemic change depends on coordinated transformations across technological, institutional, economic, political, and social dimensions (Geels, 2017; Markard et al., 2012). It also demonstrates that Iran’s transition cannot be adequately explained through a technology-centered approach because the diffusion of renewable energy is strongly conditioned by established institutional arrangements, economic structures, infrastructures, and innovation capacities.

At the landscape level, the findings showed that climate change, environmental pressures, global decarbonization trends, energy-security concerns, international climate commitments, technological developments in clean energy, and growing social awareness predominantly function as drivers of renewable-energy transition. These pressures challenge the long-term legitimacy and sustainability of the fossil-fuel-based energy system and create incentives for diversification toward cleaner alternatives. From the MLP perspective, such developments are consistent with the role of landscape pressures in destabilizing established regimes and creating windows of opportunity for emerging technologies (Geels & Schot, 2007). The findings also correspond with the broader sustainability-transition literature, which emphasizes that long-term pressures such as environmental degradation, changing societal expectations, and macro-level policy developments can alter the selection environment surrounding incumbent socio-technical configurations (Köhler et al., 2019). In Iran, these pressures are particularly important because growing energy demand, environmental concerns, and the need for greater resilience increase the strategic value of diversifying electricity generation. Nevertheless, the results indicate that landscape pressures create momentum rather than automatically producing transformation; their effectiveness depends on whether regime institutions and niche capacities can respond to the opportunities they generate.

Iran’s substantial natural potential for solar and wind energy was identified as an important but conditional landscape-level driver. The distinction between an automatic driver and a conditional driver is theoretically significant because resource abundance alone does not guarantee technological diffusion or systemic transition. Previous Iranian studies support this interpretation. Heydari identified extensive solar-energy potential and specialized human resources as important strengths for renewable-energy development, while also emphasizing that investment and policy limitations reduce the extent to which these advantages can be exploited (Heydari, 2022). Similarly, Ordu and colleagues highlighted Iran's renewable-resource potential and domestic research capabilities but showed that institutional, financial, and strategic weaknesses constrain their effective utilization (Ordu et al., 2021). Salimi and colleagues likewise demonstrated that renewable energy can make an important contribution to Iran's energy transition, although economic instability, financing restrictions, and technological constraints inhibit its expansion (Salimi et al., 2023). Thus, the present findings reinforce the argument that geographical potential must be complemented by supportive institutions, investment mechanisms, infrastructure, and technological capabilities before it can be converted into sustained transition outcomes.

The analysis further demonstrated that some landscape-level factors function as major barriers rather than drivers. Economic instability, exchange-rate fluctuations, international sanctions, banking restrictions, geopolitical uncertainty, limitations on foreign investment, and constraints on technology transfer increase the cost and risk of renewable-energy projects. These pressures restrict access to advanced equipment, capital, international collaboration, and technological knowledge. The result is consistent with previous research indicating that Iran's renewable-energy transition occurs within a particularly challenging macroeconomic and geopolitical environment. Salimi and colleagues identified sanctions, technology-transfer restrictions, exchange-rate fluctuations, and limited financial resources among the main obstacles to renewable-energy expansion (Salimi et al., 2023). Mousavi Darcheh and colleagues similarly emphasized technological dependence and limitations in domestic technological localization as critical barriers to renewable-energy development (Mousavi Darcheh et al., 2018). These findings illustrate the dual nature of the landscape: while international decarbonization and technological trends encourage transition, geopolitical and economic conditions can simultaneously weaken the capacity of domestic actors to respond to those pressures.

The most important finding of the study concerned the regime level, where the greatest concentration of barriers was observed. Fossil-fuel dependence, high energy intensity, subsidized energy prices, weak renewable-electricity pricing mechanisms, limited financing, institutional fragmentation, bureaucratic procedures, regulatory instability, infrastructure constraints, and the absence of an integrated transition roadmap collectively reinforce the stability of the incumbent energy system. This finding closely corresponds with the MLP conception of socio-technical regimes as relatively stable configurations sustained through mutually reinforcing technologies, infrastructures, regulations, markets, routines, and user practices (Geels, 2017). Historical research on electricity transitions has similarly shown that established systems are reproduced through interactions among technical structures, institutional rules, organizational networks, and social practices rather than through technology alone (Verbong & Geels, 2007). The Iranian energy regime therefore demonstrates substantial path dependence: fossil-fuel infrastructures and economic arrangements continue to reproduce conventional patterns of production and consumption and reduce the competitiveness of emerging renewable alternatives.

The prominent role of regime-level barriers also aligns with evidence concerning institutional obstacles in Iran. Aghlimoghadam showed that institutional weaknesses, interactions among dominant organizations, political-economic conditions, and characteristics of the fossil-fuel-based economy significantly restrict effective energy transition (Aghlimoghadam, 2025). The present results extend this interpretation by indicating that institutional barriers are interconnected with pricing mechanisms, subsidies, financing arrangements, infrastructure limitations, and policy instability. Accordingly, barriers should not be understood as isolated administrative deficiencies but as mutually reinforcing elements of the incumbent regime. This also helps explain why supportive renewable-energy policies may produce limited outcomes when they are introduced without corresponding changes in market structures, institutional coordination, investment conditions, and implementation capacity. In this respect, Kern's application of the MLP to innovation policy is relevant because it shows that transition policy must not only support emerging innovations but also address structural conditions that maintain incumbent regimes (Kern, 2012).

Energy subsidies and non-market-based pricing mechanisms emerged as especially significant regime-level constraints. When conventional energy remains artificially inexpensive, renewable technologies face difficulty competing on economic terms even when their long-term environmental and energy-security benefits are substantial. High investment costs, uncertain returns, weak guaranteed-purchase arrangements, and long payback periods further discourage private-sector participation. These results can be interpreted through the broader concept of socio-technical lock-in: existing economic arrangements reinforce established technologies and weaken incentives for alternative pathways. The findings are also consistent with the transition literature showing that diffusion requires changes not only in technology but also in markets, institutions, user practices, and complementary infrastructures (Kanger et al., 2019). Accordingly, renewable technologies in Iran cannot move effectively from experimentation toward mainstream deployment unless the surrounding economic and regulatory environment becomes more favorable to their adoption.

Infrastructure limitations, particularly insufficient grid capacity and difficulties in integrating variable renewable generation, were another important regime-level barrier. This finding indicates that renewable-energy expansion is dependent on complementary technological systems rather than simply on greater installation of solar and wind capacity. Renewable technologies must become embedded within electricity networks, market arrangements, operating standards, and organizational routines. Kanger and colleagues emphasized that technological diffusion should be conceptualized as societal embedding, whereby new technologies become integrated into multiple dimensions of the existing socio-technical system (Kanger et al., 2019). The present findings illustrate this principle in the Iranian context: even strong niche-level innovation or resource potential cannot transform the regime if grid infrastructure, planning procedures, and system-management capacities are unable to accommodate renewable generation. Modernizing transmission and distribution networks is therefore part of the transition itself rather than merely a secondary technical requirement.

At the niche level, the findings revealed significant transformative potential in research and development, universities, knowledge-based companies, startups, pilot projects, scientific networks, technological learning, and emerging domestic production capabilities. These factors provide protected spaces in which renewable technologies and alternative business models can be developed and tested before wider diffusion. The results are consistent with the technological innovation-system literature, which emphasizes knowledge development, entrepreneurial experimentation, network formation, legitimacy, resource mobilization, and market formation as essential processes in the development of emerging technologies (Weckowska et al., 2025). Bakhuis and colleagues likewise argue that integrating MLP and innovation-system perspectives provides stronger explanatory power because niche development cannot be separated from institutional, technological, and governance conditions (Bakhuis et al., 2024). Thus, Iran's universities, research organizations, knowledge-based firms, and emerging clean-energy enterprises constitute important sources of transition capacity.

Nevertheless, the study showed that Iran's niche-level innovation capacity remains constrained by technological gaps, dependence on imported technologies, weak domestic supply chains, inadequate testing and standardization infrastructure, shortages of specialized capabilities, and insufficient financing for high-risk innovation and commercialization. These findings are consistent with Mousavi Darcheh and colleagues, who identified technological dependence and weak localization capabilities as central barriers to renewable-energy development in Iran (Mousavi Darcheh et al., 2018). They also align with Rahmani and colleagues' analysis of Iran's wind-turbine innovation system, which demonstrated that weak innovation-system performance, inadequate technological capability, and policy failures contribute to unsuccessful transition pathways (Rahmani et al., 2022). The problem, therefore, is not the complete absence of niche innovation but the difficulty of enabling promising innovations to mature, scale up, and penetrate the dominant regime.

The findings concerning niche development also emphasize the importance of interactions among actors. Research organizations and universities may generate knowledge, but commercialization requires collaboration with firms, investors, policymakers, infrastructure operators, and end users. Geels's analysis of the micro-foundations of socio-technical transitions emphasizes that structural change is mediated by actor strategies, learning, coalition formation, institutional entrepreneurship, and changes in rules and expectations (Geels, 2020). The Iranian transition therefore depends not only on the amount of research and development conducted but on whether actors are able to coordinate resources and build networks that connect knowledge production to commercialization and deployment. Stable institutional support and university–industry collaboration are particularly relevant, as emphasized by Weckowska and colleagues in their review of technological innovation systems and sustainability transitions (Weckowska et al., 2025).

A broader interpretation of the findings shows that Iran's renewable-energy transition is characterized by an imbalance among the three MLP levels. Landscape pressures increasingly favor change, and niche capacities provide a growing set of technological and organizational alternatives, yet the incumbent regime continues to exert substantial resistance. This configuration is compatible with transition-pathway theory, according to which systemic transformation depends on the timing and alignment of landscape pressures, regime destabilization, and niche maturity (Geels & Schot, 2007). It also corresponds with Markard and Rosenbloom's argument that energy transitions progress through phases that require increasingly extensive changes in institutions, infrastructures, markets, and technologies as innovations move from emergence toward broader system transformation (Markard & Rosenbloom, 2023). Iran appears to possess several conditions necessary for greater renewable-energy deployment, but the regime has not yet been sufficiently reconfigured to enable niche innovations to achieve their full transformative potential.

Taken together, the findings suggest that technological solutions alone will be insufficient to accelerate the renewable-energy transition in Iran. Sustainable transition requires coordinated interventions that simultaneously address regime reform, niche strengthening, and responses to landscape pressures. This conclusion supports contemporary sustainability-transition scholarship, which increasingly emphasizes governance, policy mixes, agency, innovation, institutional change, and cross-sector coordination (Köhler et al., 2019). It also supports the integrated perspective proposed by Bakhuis and colleagues, according to which combining insights from the MLP, technological innovation systems, and transition governance can provide a more comprehensive understanding of transition dynamics (Bakhuis et al., 2024). Accordingly, Iran's renewable-energy transition should be viewed as a co-evolutionary process in which reforms in energy pricing, financing, governance, infrastructure, innovation systems, and technological capabilities must reinforce one another. The principal implication of the findings is that the dominant bottleneck lies not in the absence of renewable resources or technological possibilities but in the institutional and economic capacity to translate landscape pressures and niche innovations into durable regime transformation.

The present study has several limitations that should be considered when interpreting its findings. First, the analysis was based primarily on published scientific literature, technical reports, and policy documents; therefore, the identified drivers and barriers depend on the scope, availability, and quality of the reviewed sources. Some emerging or locally specific factors may not have been sufficiently represented in the available literature. Second, the classification of factors within the landscape, regime, and niche levels required analytical interpretation, and some factors may operate across more than one level or change their role over time. Third, the study identified and classified transition factors but did not quantitatively determine their relative importance, causal strength, or priority. Finally, because the analysis focused specifically on Iran, the findings are shaped by the country's distinctive energy structure, institutional environment, economic conditions, and geopolitical context and should therefore be generalized to other countries with caution.

Future studies should complement the present qualitative framework with empirical and quantitative approaches that assess the relative importance and causal relationships among the identified factors. Expert surveys, Delphi techniques, structural equation modeling, system dynamics, fuzzy cognitive mapping, and multi-criteria decision-making methods could be employed to rank drivers and barriers and investigate their interdependencies. Longitudinal studies would also be useful for examining how the roles of landscape, regime, and niche factors evolve as renewable technologies diffuse and policy conditions change. Technology-specific analyses of solar, wind, energy storage, distributed generation, and green hydrogen could determine whether transition dynamics differ across technological niches. Comparative studies involving countries with similar fossil-fuel dependence or comparable economic and institutional conditions could further distinguish context-specific barriers from more general transition mechanisms. Future research could also examine the perspectives and strategies of policymakers, private investors, renewable-energy firms, universities, consumers, and civil-society organizations to provide a more actor-centered understanding of transition processes.

In practice, accelerating Iran's renewable-energy transition requires coordinated action across the energy system rather than isolated technological projects. Policymakers should develop a stable and binding national transition roadmap with measurable targets, transparent responsibilities, and mechanisms for monitoring implementation. Gradual reform of energy subsidies and pricing structures should be accompanied by protections for vulnerable consumers and redirection of resources toward renewable-energy investment. Financing should be strengthened through long-term purchasing arrangements, green financing instruments, investment guarantees, and mechanisms that reduce private-sector risk. Grid modernization, energy-storage development, distributed generation, and simplified project-connection procedures should receive greater priority. Simultaneously, stronger support should be provided for universities, knowledge-based companies, domestic manufacturers, pilot projects, technology localization, testing facilities, and specialized workforce development. Improved coordination among public institutions, research organizations, industry, investors, and electricity-sector operators would help ensure that technological innovations can progress from experimentation and commercialization to widespread deployment within the national energy system.

Authors' Contributions

Authors contributed equally to this article.

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In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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