Proceedings of the 10th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/2026.35754

Research on Anthropogenic Energy Transition, Ecological Spatiotemporal Evolution and Environmental Engineering Regulation Mechanisms in the Context of the Anthropocene

Bifei Xu

Energy Environment and Spatial Information Engineering, Anqing Normal University, Anqing, China
3086439571@qq.com

Abstract. In the Anthropocene, human social activities have replaced natural processes as the core force dominating the evolution of Earth's ecosystems. Compound ecological imbalance caused by energy development and transition has become a major manifestation of regional human-land contradiction. From an interdisciplinary perspective integrating human geography and environmental science, this paper focuses on the characteristics of energy-induced ecological imbalances, human-driven influencing mechanisms and optimal regulation paths. It sorts out the theoretical framework of human-energy-land coupling, summarizes two types of ecological imbalance, namely cumulative pollution risks from fossil energy development and spatial disturbance from new energy construction, and reveals the human-driven mechanisms of energy-ecological problems from the dimensions of socioeconomics and land space, and constructs a multi-dimensional comprehensive regulation system focusing on zonal control, spatial matching and cross-regional coordination. Adaptive strategies for coordinated regional development in line with energy transition are proposed. The study aims to alleviate the spatial mismatch and functional imbalance between energy development and ecological protection, providing theoretical support and practical reference for regional low-carbon transition and coordinated human-land governance in the Anthropocene.

Keywords: Anthropocene, Energy Structure Transition, Human-Land Coupling, Environmental Engineering Regulation

1. Introduction

Against the backdrop of the Anthropocene, the evolution of Earth's ecosystems has entered a new stage dominated by humans [1]. Large-scale energy development accompanying industrialization and urbanization has completely altered the ecological evolution laws of the Holocene's natural steady state, making energy activities a core trigger for regional environmental degradation and human-land relationship imbalance [2]. With the advancement of the dual-carbon strategy, regional energy structures are undergoing accelerated iteration. Legacy pollution from traditional fossil

DOI: 10.54254/2754-1169/2026.35754

energy overlaps with new ecological conflicts arising from new energy development, forming compound and spatialized modern energy-ecological problems [3].

Current academic research mostly focuses on the evolution of energy patterns or the analysis of single ecological effects, while systematic research on "human-driven factors – energy disturbance – ecological imbalance – comprehensive regulation" remains insufficient, lacking a holistic regulation system adapted to the characteristics of the Anthropocene [4]. On this basis, this paper analyzes the characteristics and human-driven mechanisms of energy-induced ecological imbalances, with a core focus on comprehensive regulation strategies, constructing multi-level coordinated governance paths to support the green transition of regional energy and the coordinated development of human-land systems [5].

2. Theoretical connotation of human-energy-land coupling

The core characteristics of ecological evolution in the Anthropocene include human dominance, systematic disturbance and interactive coupling. As a key link connecting human society and natural ecosystems, changes in the development scale, consumption structure and spatial layout of the energy system directly induce systematic responses in the regional ecological environment, endowing contemporary ecological problems with distinct anthropogenic, cumulative and spatially heterogeneous features.

The human-energy-land coupling theory reveals the dynamic feedback mechanism among the three: the spatial pattern of human activities shapes regional energy development models, changes in energy development disturb the ecological environment pattern, and ecological carrying capacity in turn restricts human spatial development and energy layout.

3. Spatiotemporal evolution of regional energy patterns and eco-environmental effects

3.1. Spatial differentiation and cumulative effects of fossil energy pollution disturbance

Industrial agglomeration areas centered on fossil energy form high-intensity anthropogenic pollution units, with persistent eco-environmental effects such as accumulation of atmospheric pollutants, superimposed carbon emissions and enrichment of heavy metals in soil. Constrained by human geographical factors including urban spatial layout, transportation location and industrial agglomeration level, fossil energy consumption exhibits significant spatial agglomeration characteristics, resulting in an uneven distribution of regional ecological pressure. Such long-term and cumulative pollution not only causes short-term environmental quality degradation but also leaves persistent stratigraphic sedimentary records, representing the most typical form of anthropogenic ecological disturbance during the "Great Acceleration" phase of the Anthropocene.

3.2. New ecological conflicts and environmental risks in the energy transition process

The global low-carbon energy transition has effectively mitigated conventional pollution and carbon cycle imbalances induced by traditional fossil energy. However, the large-scale deployment and development of renewable energy such as wind power, photovoltaic power and hydropower has spawned a series of new human-ecological contradictions. The occupation of large areas by new energy facilities reshapes the original land use pattern, disrupts regional vegetation community structure and hydrological ecological balance, and triggers new ecological risks such as habitat fragmentation, light pollution and noise pollution. Different from the disturbance mechanism of

DOI: 10.54254/2754-1169/2026.35754

chemical pollution from fossil energy, the ecological disturbance of renewable energy is characterized primarily by the destruction of spatial patterns and reconstruction of ecological structures, imposing new requirements on the ecological restoration technologies, governance concepts and control models of environmental engineering in the new era [6].

4. Human geographical driving mechanisms of regional energy structure evolution

4.1. Socioeconomic factor drivers

Population agglomeration and urbanization are the fundamental human driving forces behind the expansion of regional energy demand. Highly urbanized regions concentrate massive energy consumption for industrial production and residential use, forming core circles of high-intensity energy consumption. Industrial structure upgrading is the core leading factor in energy structure transition. Regions with concentrated high-energy-consuming industries exhibit heavy reliance on fossil energy supply, while urban regions dominated by service and high-tech industries are more prone to promoting clean energy substitution, ultimately leading to differentiated energy consumption patterns and eco-environmental effects across different urban functional units.

4.2. Spatial layout and land use drivers

The reconstruction of human land use patterns reshapes the distribution of energy infrastructure at the spatial level. Uncontrolled expansion of urban construction land occupies and compresses original ecological spaces, while the fixed layout of energy infrastructure further locks in the spatial pattern of regional energy consumption. Differences in land development intensity across regions directly lead to spatial imbalance in energy disturbance intensity, ultimately triggering spatial differentiation in regional eco-environmental quality. Such reconstruction of energy patterns dominated by human spatial activities is a core trigger for prominent regional human-land contradictions in the Anthropocene [7].

5. Environmental engineering regulation pathways for human-energy-land coupling imbalance

5.1. Implement differentiated zonal control to resolve spatial ecological imbalance

Precise zonal control is carried out in response to spatial differences in the type and intensity of regional energy disturbance. In industrial core areas with concentrated fossil energy, the focus is on eliminating cumulative pollution risks by strictly controlling increments of high-energy-consuming industries, phasing out backward production capacity, promoting low-carbon industrial transformation, and gradually restoring damaged ecological foundations. In ecologically sensitive areas with concentrated new energy, a negative list for energy development is strictly implemented to avoid core ecological spaces, control development intensity, and carry out targeted ecological restoration in damaged developed areas to curb the spread of habitat fragmentation. In reserve areas with sound ecology and weak development, priority is given to protection with moderate development, and ecological buffer spaces are reserved to achieve zonal balance between energy development and ecological protection.

DOI: 10.54254/2754-1169/2026.35754

5.2. Optimize energy spatial layout to achieve functional coupling and matching of humans, energy and land

To rectify spatial mismatches between territorial planning and energy layout, the energy development system is fully integrated into the overall territorial spatial planning. It strengthens coordinated management of functional boundaries for industrial, residential, ecological and energy development spaces to avoid spatial conflicts at the source. In line with urbanization patterns and population distribution characteristics, clean energy facilities are deployed in adaptation to urban functional positioning to achieve precise matching between energy supply and regional development needs. Unreasonable energy facilities adjacent to residential areas and core ecological areas are systematically relocated and upgraded to reduce the interference of energy development on residential environments and original ecosystems, constructing a benign coupling pattern with spatial adaptation, ecological controllability and efficient supply.

5.3. Build a cross-regional coordination system to promote high-quality development of human-land systems

Based on long-term governance needs, a trinity cross-regional coordination mechanism integrating energy transition, ecological protection and social development is constructed. In terms of energy, continuous efforts are made to advance the low-carbon substitution of energy structures and scale up clean energy development, establishing an efficient, low-carbon, safe and stable modern energy system. In terms of ecology, adapting to the new ecological characteristics of the Anthropocene, a whole-chain governance model of "preventive control, dynamic monitoring and ecological restoration" is established, focusing on the remediation of landscape degradation and habitat damage caused by new energy development to maintain the integrity of ecosystems. In the human dimension, urbanization construction, economic growth and ecological conservation are coordinately advanced. Ecological supervision and benefit evaluation mechanisms for energy development require improvement, and ecological constraints must be imposed throughout the entire process of energy development. This will help promote the transformation of regional human-land systems from antagonistic imbalance toward coordinated coupling and high-quality development.

6. Conclusion

This paper systematically elaborates on the coupled evolution mechanisms of regional energy structures, human geographical patterns and ecological environment systems in the Anthropocene, exploring differentiated environmental engineering regulation pathways for energy-induced ecological imbalance. The study confirms that human social and spatial activities are the fundamental driving forces behind the reconstruction of regional energy patterns and the differentiation of ecological environments. Distinct types of energy exhibit significant differences in ecological disturbance mechanisms: fossil energy is characterized by cumulative chemical pollution and persistent geological-ecological imprints, while renewable energy is manifested primarily as structural ecological space destruction and habitat disturbance. The spatial mismatch between human spatial layout and energy development activities is the core crux of contemporary regional human-land system imbalance. This study has certain limitations: it only reveals the macro-coupling laws of regions and fails to achieve refined quantitative decomposition and long-term dynamic simulation of multiple driving factors. Future research can rely on long-term remote sensing

DOI: 10.54254/2754-1169/2026.35754

monitoring data and high-precision econometric models to conduct in-depth analysis of how micro human activities drive energy–ecological evolution and optimize regulation schemes in combination with regional economic and technical constraints, providing more precise theoretical support and a practical basis for regional low-carbon transition, comprehensive ecological governance and coordinated and sustainable human-land development in the Anthropocene.

References

[1] Malhi, Y. (2017). The concept of the Anthropocene. *Annual Review of Environment and Resources, 42*, 77-104.
[2] Marris, E. (2009). Ragamuffin Earth: The rise of novel ecosystems. *Nature, 460*(7253), 448-453.
[3] Hobbs, R. J., Arico, S., Aronson, J., et al. (2006). Novel ecosystems: Theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography, 15*(1), 1-7.
[4] Duan, J. C., & Tan, J. H. (2022). Optimization of regional environmental engineering system under the background of energy transition. *Acta Scientiae Circumstantiae*.
[5] Zhang, J. X., & He, H. M. (2021). Reconstruction of human-land relationship and research shift in geography from the perspective of the Anthropocene. *Acta Geographica Sinica*.
[6] Wang, Y., & Zhou, Z. X. (2023). Spatiotemporal pattern evolution of energy consumption and its eco-environmental effects in China. *Acta Ecologica Sinica*.
[7] Hao, J. M., & Ma, G. D. (2020). *Air Pollution Control Engineering*. Higher Education Press.