Research on the Integration of Artificial Intelligence and Zero-Emission Technology in the Era of Digital Economy

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ABSTRACT Against the dual backdrop of digital economy permeating all global socio-economic sectors and carbon neutrality goals becoming a worldwide consensus, the deep integration of artificial intelligence (AI) and zero-emission technologies has emerged as a pivotal pathway to drive industrial green transformation, address energy-environmental challenges, and achieve high-quality sustainable development. Grounded in the technological characteristics and development trends of the digital economy era, this study systematically analyzes the intrinsic logic and core mechanisms of AI-zero emission technology convergence. It examines practical applications and implementation outcomes in key sectors including energy, industry, construction, and transportation, while conducting in-depth analysis of current challenges such as computational energy consumption, technical barriers, data silos, and institutional deficiencies. Targeted optimization strategies are proposed encompassing technological breakthroughs, system architecture development, policy safeguards, and ecosystem cultivation. The research aims to provide theoretical foundations and practical references for deepening AI-zero emission technology integration, advancing zero-carbon society construction, and achieving coordinated progress between economic development and ecological conservation..

Keywords digital economy; artificial intelligence; zero-emission technology; technology convergence; carbon neutrality; green transition.

I.INTRODUCTION

1.1 Research Background

The digital economy has now become a pivotal engine driving global economic growth. Cutting-edge technologies such as big data, cloud computing, artificial intelligence, and the Internet of Things are evolving at breakneck speed, reshaping production methods, lifestyles, and governance systems while propelling societies into a new era of digitalization, intelligence, and connectivity. Meanwhile, escalating global climate change, environmental degradation, and energy resource shortages have made achieving carbon peaking and carbon neutrality goals, along with transitioning to zero emissions, a shared strategic imperative for nations worldwide. China has explicitly outlined its "Dual Carbon" strategic objectives, committed to driving comprehensive green transformation across socioeconomic development, building a clean, low-carbon, safe, and efficient energy system, fostering a zero-carbon industrial ecosystem, and striking a balance between economic growth and environmental protection.

Zero-emission technologies serve as the cornerstone for achieving carbon neutrality goals, encompassing multiple domains such as clean energy development, energy efficiency enhancement, carbon capture, utilization and storage (CCUS), and waste resource utilization. Traditional zero-emission technologies face limitations including insufficient regulatory precision, delayed response capabilities, weak system adaptability, and inadequate global optimization capacity, making them ill-suited for complex and dynamic production scenarios and energy systems. As a core technology of the digital economy, artificial intelligence possesses exceptional data processing capabilities, deep learning algorithms, intelligent decision-making, and precise control mechanisms. It can overcome the bottlenecks of conventional zero-emission technologies by enabling comprehensive perception, prediction, optimization, and management of energy consumption, carbon emissions, and pollutant discharge throughout the entire process. This advancement drives the transformation of zero-emission technologies from single-point optimization to system coordination, from reactive responses to proactive forecasting, and from coarse control to refined governance.

Empowered by the digital economy, the integration of artificial intelligence and zero-emission technologies transcends mere technical layering. It involves profound mechanistic coupling, scenario symbiosis, and value co-creation that not only enhances the efficiency and applicability of zero-emission technologies but also drives the AI industry toward green, low-carbon, and energy-efficient development pathways, achieving a win-win scenario for technological innovation and ecological conservation. While pilot applications of this dual-technology convergence have been implemented across multiple sectors, the field remains in its nascent stage. Challenges persist including insufficient systematic theoretical research, practical implementation barriers, and incomplete supporting systems. Urgent in-depth studies are needed to clarify integration logic, address developmental bottlenecks, and unlock the synergistic benefits of technological convergence.

1.2 Research Significance

Theoretically, this study establishes a theoretical framework integrating artificial intelligence with zero-emission technologies based on the characteristics of the digital economy era. It analyzes the intrinsic mechanisms, operational processes, and value creation pathways of their convergence, enriching interdisciplinary research achievements in digital economy and green low-carbon fields. Addressing the shortcomings of existing studies that prioritize single-technology applications over systemic integration analysis, this work provides theoretical references and conceptual insights for subsequent academic research.

In practical terms, this study systematically analyzes typical scenarios of technological convergence and existing challenges, proposing actionable optimization strategies. These solutions can provide intelligent zero-carbon transition frameworks for high-emission sectors including energy, manufacturing, construction, and transportation. By helping enterprises reduce energy consumption, lower emissions, and enhance operational efficiency, the research also offers critical insights for policymakers to formulate targeted policies, refine regulatory systems, and foster green industrial ecosystems. Ultimately, these efforts will accelerate societal transition toward carbon neutrality, paving the way for achieving global climate goals.

1.3 Current Research Status at Home and Abroad

Foreign research in this field began earlier, with scholars focusing on applications of artificial intelligence in energy dispatching, carbon emission accounting, climate modeling, and industrial energy conservation. Key studies have examined the practical effectiveness of machine learning and deep learning algorithms in renewable energy power forecasting, smart grid regulation, and industrial process optimization, demonstrating AI's significant role in enhancing zero-emission technology efficiency and reducing emission reduction costs. Some research addresses AI's energy consumption challenges, proposing concepts like green AI and low-carbon computing power to balance technological empowerment with emission reduction efforts. However, most international studies remain confined to single-scenario applications, with limited systematic research on cross-industry and full-chain technological integration, as well as insufficient targeted analyses tailored to developing countries' specific contexts.

Domestic research focusing on the "dual carbon" goals primarily explores the practical implementation of artificial intelligence in zero-carbon industrial parks, smart grids, green manufacturing, and low-carbon transportation sectors. It systematically analyzes policy environments and case studies for technological integration while identifying existing challenges in technology, funding, and talent acquisition. In recent years, scholars have increasingly examined the deep coupling mechanisms between AI and zero-carbon technologies, shifting research focus from application descriptions to mechanism analysis and policy strategies. However, current studies still face limitations such as incomplete theoretical frameworks, superficial problem analysis, and insufficiently targeted solutions. Further research is needed to deepen understanding of dynamic technological evolution, risk mitigation strategies, and ecosystem development within the digital economy context.

1.4 Research Content and Methods

The primary research objectives of this paper include: defining the core concepts of artificial intelligence and zero-emission technologies in the digital economy era, tracing the developmental trajectory of technological convergence; analyzing the intrinsic mechanisms, core advantages, and driving factors behind their integration; summarizing application scenarios, implementation models, and outcomes of technological convergence in key sectors; assessing the practical challenges and underlying causes hindering technological integration; and proposing strategic recommendations to facilitate deeper integration between AI and zero-emission technologies.

In terms of research methodology, we employ literature review to analyze domestic and international academic works, policy documents, and industry reports to establish theoretical foundations. Case studies are conducted by examining technological integration practices in representative industries and projects to identify best practices and challenges. Systematic analysis is applied to treat technological integration as a complex system, comprehensively evaluating factors such as technology, market dynamics, policy frameworks, and talent resources to propose holistic optimization strategies.

II. Related Concepts and Theoretical Foundations

2.1 Definition of Core Concepts

2.1.1 Digital Economy

The digital economy is a new economic paradigm that takes data resources as key production factors, modern information networks as primary carriers, and digital technology applications as core drivers. Through deep integration of digital technologies with the real economy, it continuously enhances production efficiency, optimizes resource allocation, and reshapes economic structures. Characterized by data-driven approaches, cross-sector integration, inclusive accessibility, and green efficiency, the digital economy encompasses four key components: digital industrialization, industrial digitization, digital governance, and data valorization. It serves as a vital pillar for promoting high-quality economic development and facilitating green transformation.

2.1.2 artificial intelligence

Artificial intelligence (AI) is an interdisciplinary technology integrating computer science, mathematics, psychology, neuroscience, and other fields. It aims to simulate, extend, and enhance human intelligence by enabling intelligent behaviors such as perception, cognition, decision-making, and execution. In the zero-emission sector, commonly used AI technologies include machine learning, deep learning, computer vision, natural language processing, intelligent optimization algorithms, and digital twins. These technologies possess core capabilities like data processing, predictive analytics, intelligent control, and autonomous learning, enabling precise emission reduction and efficient energy utilization in complex scenarios.

2.1.3 Zero Emission Technology

Zero-emission technologies refer to a comprehensive set of solutions designed to achieve near-zero emissions of greenhouse gases, pollutants, and waste throughout production and daily life processes, thereby minimizing ecological impacts. Broadly defined, these technologies fall into three categories: First, clean energy substitution technologies, including renewable energy development and utilization methods such as solar, wind, hydro, hydrogen, and biomass energy; Second, energy efficiency enhancement technologies encompassing industrial energy conservation, building energy efficiency, transportation energy savings, and equipment energy reduction; Third, end-of-pipe treatment and recycling technologies like carbon capture, utilization, and storage (CCUS), waste resource recovery, and advanced pollutant treatment systems.

2.2 Theoretical Basis of Technological Integration

2.2.1 Theory of Technology Integration

Technological convergence refers to the process where technologies from different fields interpenetrate, intersect, and integrate to form new technological systems, products, and application models. In the digital economy era, the circulation and sharing of data elements provide the foundation for technological convergence. The versatility and adaptability of artificial intelligence enable deep integration with various zero-emission technologies, breaking down industry and technological barriers. This fosters intelligent zero-carbon innovations, new business models, and operational paradigms, achieving a synergistic effect where 1+1>2.

2.2.2 Sustainable Development Theory

The theory of sustainable development emphasizes the coordinated advancement of economic growth, social progress, and ecological conservation, aiming to establish a development model that meets the needs of current generations without compromising future generations' capacity to fulfill their own requirements. The integration of artificial intelligence with zero-emission technologies aligns perfectly with sustainable development principles. By leveraging intelligent solutions, this approach enhances resource utilization efficiency, reduces environmental pollution, optimizes energy structures, and balances economic, social, and ecological benefits, thereby steering socio-economic development toward a green and sustainable path.

2.2.3 System Optimization Theory

System optimization theory emphasizes a holistic approach to coordinate and regulate all elements and components of complex systems, aiming to maximize overall system efficiency. Traditional zero-emission technologies primarily focus on optimizing individual processes, lacking comprehensive coordination capabilities. Artificial intelligence, however, can integrate end-to-end process data to build systematic optimization models. By dynamically regulating the entire energy chain — from production and transmission to consumption and recycling — it achieves global optimization in carbon emissions, energy consumption, and costs, driving the transition of zero-emission systems from localized improvements to comprehensive upgrades.

III. Mechanisms and Advantages of Artificial Intelligence and Zero-Emission Technology Integration in the Digital Economy

3.1 Intrinsic Mechanism of Technological Convergence

The integration of artificial intelligence and zero-emission technologies represents a deep coupling of data, algorithms, computing power, and low-carbon technologies. With data as the core link, algorithms as the core engine, computing power as the foundational support, and zero-emission technologies as the implementation vehicle, it forms a closed-loop operational system encompassing "perception — analysis — decision-making — execution — feedback."

At the perception level, leveraging IoT sensors, satellite remote sensing, and intelligent monitoring devices, massive data on energy consumption, carbon emissions, pollutant emissions, and production operations are collected in real-time. This breaks down data barriers across production, energy, and emission ends, establishing a comprehensive carbon data perception network to provide data support for technological integration.

At the analytical level, artificial intelligence algorithms are employed to perform data cleaning, mining, and deep learning on massive datasets. This enables the identification of energy consumption and emission patterns, prediction of energy demand and carbon emission trends, as well as analysis of emission reduction potential and weak links. By overcoming the limitations of traditional data analysis, it achieves precise profiling of complex systems.

At the decision-making level, based on data analysis results and integrating multiple conditions such as emission reduction targets, cost constraints, and operational safety, intelligent optimization algorithms generate optimal emission reduction plans, energy dispatching plans, and production control plans. This achieves multi-objective collaborative optimization, replacing manual empirical decision-making and enhancing the scientific rigor and precision of decision-making.

At the execution and feedback level, intelligent decision-making instructions are issued to various zero-emission devices and production equipment to achieve automated and refined regulation. Simultaneously, operational data is continuously collected and fed back to the AI system for autonomous learning and iteration, enabling continuous optimization of control strategies and enhancing the compatibility and effectiveness of technological integration.

3.2 Core Driving Factors of Technological Convergence

Policy-driven initiatives serve as a critical prerequisite. Countries worldwide have introduced carbon neutrality policies and digital economy development plans, prioritizing intelligent zero-carbon transition as a key strategy. China has enacted multiple policies to support the integrated development of artificial intelligence and green low-carbon technologies, providing a favorable policy environment and institutional safeguards for technological convergence.

Technological iteration serves as the core driving force. Continuous upgrades in artificial intelligence algorithms, sustained reductions in computational cost, increasing maturity of Internet of Things (IoT) and big data technologies, as well as breakthroughs in zero-emission technologies have provided a solid technical foundation for their integration, lowered the integration threshold, and expanded application scenarios.

Market demand serves as the intrinsic driving force. High-emission industries face stringent environmental assessments and cost pressures, necessitating efficient and low-cost zero-carbon transition solutions for enterprises. The growing consumer awareness of green consumption is compelling the industrial sector to accelerate green upgrades, thereby promoting the rapid integration and implementation of artificial intelligence with zero-emission technologies.

Digital economy empowerment serves as a critical safeguard. The market-oriented allocation of data elements is accelerating, with continuous improvements in digital infrastructure, facilitating cross-industry and cross-regional data circulation and sharing, breaking down information barriers, and providing sufficient data support for artificial intelligence algorithm training and system optimization, thereby accelerating the process of technological convergence.

3.3 Unique advantages of technology convergence

3.3.1 Enhancing Emission Reduction Precision

Traditional emission reduction technologies rely on fixed parameters and manual regulation, which are prone to issues such as excessive emission reduction or insufficient reduction, leading to severe resource waste. Artificial intelligence (AI) enables refined control by time period, region, and equipment, allowing for customized emission reduction strategies tailored to different scenarios. This approach precisely matches energy supply and demand, minimizes ineffective energy consumption and emissions, and enhances emission reduction efficiency.

3.3.2 Implementation of Dynamic Adaptive Regulation

In the face of uncertain factors such as weather changes, production fluctuations, and energy supply-demand variations, traditional zero-emission technologies exhibit delayed responses and struggle to adapt rapidly. Artificial intelligence (AI) possesses autonomous learning and real-time iteration capabilities, enabling timely adjustments to control strategies in response to external environmental changes. This facilitates dynamic adaptive operation, ensuring stable and efficient performance of zero-emission systems.

3.3.3 Promoting System Optimization Across the Entire Value Chain

Artificial intelligence breaks through the optimization limitations of single processes and individual devices by integrating resources across the entire energy chain—from production, transmission, and utilization to recycling, as well as production, emissions, and governance. It comprehensively balances emission reduction targets, economic benefits, and operational safety to achieve global optimization, thereby avoiding overall efficiency losses caused by localized optimizations.

3.3.4 Reducing Transformation Costs

Through intelligent prediction, intelligent scheduling, and intelligent operation and maintenance, we reduce equipment idling losses, minimize energy waste, lower labor costs, extend equipment service life, optimize emission reduction resource allocation, avoid redundant investments, and help enterprises achieve zero-carbon transition at lower costs, thereby enhancing the economic benefits and promotion value of technological integration.

3.3.5 Empowering Digital Governance

Leveraging artificial intelligence technology, an intelligent carbon monitoring, carbon accounting, and carbon supervision platform is established to achieve real-time verifiability, traceability, and validation of carbon emission data. This enhances the efficiency of government environmental regulation, facilitates the efficient operation of carbon trading markets, and promotes the digitalization, intelligence, and transparency of zero-carbon governance.

IV. Application Scenarios and Practices of Artificial Intelligence Integration with Zero-Emission Technologies

4.1 Energy Sector: Building a Smart Zero-Carbon Energy System

The energy sector is a major source of carbon emissions and a core area for zero-emission transition. The integration of artificial intelligence with clean energy technologies and grid dispatching technologies can address challenges such as instability in renewable energy generation, imprecise grid dispatching, and low energy utilization efficiency.

In the renewable energy generation sector, artificial intelligence algorithms are employed to accurately predict natural conditions such as wind speed, sunlight intensity, and precipitation. This enhances the precision of power output forecasting for wind and solar installations, mitigates grid impacts caused by the randomness and volatility of renewable energy generation, and improves renewable energy integration rates. Meanwhile, intelligent operation and maintenance systems enable real-time monitoring of wind and solar equipment status, facilitate early fault detection, reduce downtime-related losses, and boost overall power generation efficiency.

On the grid dispatching side, an AI-powered smart grid dispatching system is established to integrate data from power generation, grid operations, and load management. This system enables integrated coordination among generation, grid, load, and storage resources, dynamically allocates power resources, prioritizes clean energy scheduling, reduces thermal power usage, and ultimately builds a zero-carbon smart grid. For energy storage systems, AI optimizes charging/discharging strategies to enhance equipment utilization efficiency, stabilize grid load fluctuations, and ensure reliable power supply.

In the field of novel clean energy such as hydrogen energy, artificial intelligence facilitates the optimization of the entire hydrogen production, storage, transportation, and application chain. It enables precise control of hydrogen production parameters, reduces hydrogen production costs, enhances hydrogen storage and transportation safety, and promotes hydrogen as a critical component of the zero-carbon energy system.

4.2 Industrial Sector: Achieving Green Intelligent Manufacturing

The industrial sector, characterized by high energy consumption and substantial emissions, represents a critical and challenging domain in the zero-carbon transition. The integration of artificial intelligence with industrial energy conservation, clean production, and circular utilization technologies is driving the transformation of industrial production from high-carbon extensive models to low-carbon intensive models.

In production process optimization, industrial digital twin systems are established to leverage AI for real-time monitoring of production equipment parameters. This enables process optimization, production rhythm adjustment, and reduction of idle energy consumption and waste generation, achieving comprehensive energy conservation and emission reduction throughout the production cycle. For instance, in energy-intensive industries such as steel, chemicals, and building materials, AI precisely controls furnace temperature, pressure, and flow rates to lower energy consumption per unit product while minimizing greenhouse gas emissions and pollutant discharge.

In equipment operation and maintenance, AI-powered intelligent early warning and predictive maintenance technologies are adopted to replace traditional periodic inspections. This approach enables early identification of equipment failures, prevents energy consumption spikes and emission exceedances caused by abnormal operations, enhances operational efficiency, and prolongs equipment service life.

In terms of circular utilization, AI assists in industrial waste classification, recycling, and resource recovery by accurately identifying waste types and recycling value, optimizing recycling processes, enhancing waste resource utilization rates, and achieving zero emissions in industrial production closed-loop systems. Meanwhile, leveraging AI to establish a carbon footprint accounting system enables comprehensive tracking of carbon emissions throughout the entire product lifecycle, supporting enterprises in meeting carbon reduction targets.

4.3 Construction Sector: Building Zero-Carbon Smart Buildings

The construction industry accounts for a significant proportion of total societal energy consumption, with HVAC systems, lighting, and water/electricity supply being the primary sources of building energy use. By integrating artificial intelligence with green building technologies, we aim to develop zero-carbon smart buildings and zero-carbon industrial parks.

In building energy management, AI-powered intelligent building control systems analyze real-time data including indoor/outdoor temperatures, lighting conditions, and occupancy patterns to dynamically regulate HVAC systems, lighting, and ventilation operations. This smart approach optimizes energy consumption while maintaining comfort levels. By integrating photovoltaic panels and energy storage solutions, the systems achieve full energy self-sufficiency with surplus power fed into the grid, ultimately realizing zero-energy building objectives.

During the architectural design phase, AI algorithms are employed to optimize building layouts, material selection, and structural configurations, enhancing natural lighting and ventilation efficiency while reducing reliance on HVAC systems. This approach minimizes energy consumption and carbon emissions at the source. In zero-carbon park development, AI systems coordinate energy supply, production operations, and carbon emission controls to achieve comprehensive zero-emission performance, creating integrated green parks that combine energy efficiency, low-carbon practices, and smart technologies.

4.4 Transportation Sector: Developing Low-Carbon Intelligent Transportation

Carbon emissions in the transportation sector continue to rise, with fuel-powered vehicles and congested road conditions being the primary emission sources. The integration of artificial intelligence with new energy transportation and intelligent transportation technologies aims to establish a green, low-carbon, efficient, and convenient intelligent transportation system.

In terms of transportation vehicles, AI facilitates the development of zero-carbon transportation solutions such as new energy vehicles, hydrogen fuel cell vehicles, electric ships, and electric aircraft. It optimizes battery management systems, enhances range and energy utilization efficiency, reduces costs of new energy vehicles, and accelerates the replacement of fossil fuel-powered vehicles.

In terms of traffic management, the AI-powered intelligent traffic signal system monitors real-time road conditions and vehicle flow, dynamically adjusts traffic light durations to alleviate congestion and reduce vehicle idling emissions. Concurrently, an intelligent mobility platform is established to optimize public transportation routes, promote shared mobility models, enhance traffic resource utilization efficiency, and decrease overall transportation-related carbon emissions.

In logistics transportation, AI optimizes route planning and cargo loading schemes to reduce empty load rates and transportation mileage, promotes the adoption of new energy logistics vehicles, and establishes a green and intelligent logistics system, achieving zero-emission transformation in logistics transportation.

4.5 Ecological Governance Sector: Facilitating Precision Zero-Carbon Control

Artificial intelligence integrates with ecological monitoring, carbon sink enhancement, and pollutant control technologies to achieve intelligent and refined environmental management. By combining satellite remote sensing, ground-based sensors, and AI, real-time monitoring of air, water, and soil pollution levels enables precise emission source identification and rapid environmental response. AI algorithms optimize carbon sink management in forests, wetlands, and grasslands to boost ecosystem carbon sequestration capacity. The system also supports CCUS (Carbon Capture, Utilization, and Storage) technology optimization, enhancing carbon capture, utilization, and storage efficiency while reducing end-of-pipe emission reduction costs.

V. Practical Challenges in Integrating Artificial Intelligence with Zero-Emission Technologies

5.1 Significant energy consumption contradictions inherent in artificial intelligence

The operation of artificial intelligence relies on massive computational power, where increased processing capacity comes with substantial energy consumption — particularly in scenarios like large model training and big data processing, which demand enormous energy resources. Currently, some data centers and computing facilities in China still depend on thermal power generation, with clean energy sources accounting for a limited proportion. This results in the AI industry generating significant carbon emissions, creating a paradox where "intelligent emission reduction actually leads to increased emissions." Unless the inherent green and low-carbon challenges of AI are addressed, its net benefits in enabling zero-emission solutions will be greatly diminished, potentially exacerbating energy shortages and environmental pressures.

5.2 Barriers to technological convergence remain unbroken

China's technological shortcomings in core areas remain evident, with continued reliance on foreign technologies in high-end AI chips, advanced algorithms, and zero-carbon equipment. Dependence on external technologies constrains the depth and quality of technological integration. AI systems exhibit poor compatibility with traditional zero-emission technologies, as some AI solutions fail to integrate with existing industrial equipment and energy infrastructure, resulting in high retrofitting costs and operational challenges that small and medium-sized enterprises struggle to afford. The nation's innovation capabilities in cross-domain technology integration remain weak, with limited interdisciplinary R&D achievements. Most applications still operate at superficial integration levels, lacking deep mechanistic coupling at the fundamental technical level.

5.3 Coexistence of Data Silos and Data Security Issues

Data serves as the cornerstone of technological convergence, yet current data silos persist across industries, government sectors, and enterprises. Energy metrics, production records, emission data, and environmental monitoring information remain fragmented, creating numerous data islands. AI algorithms lack sufficient high-quality data support, hindering their ability to achieve precise regulation and intelligent optimization. Moreover, carbon emission data and corporate production records involve trade secrets and public safety concerns, exposing data sharing processes to risks of leaks and misuse. Inadequate data security mechanisms further constrain data circulation and utilization.

5.4 Severe shortage of compound-type talent supply

The integration of artificial intelligence with zero-emission technologies requires interdisciplinary professionals who master both AI algorithms and digital technologies while possessing expertise in energy conservation, environmental protection, and engineering systems. Currently, China's higher education institutions lag in establishing relevant academic programs, and the cross-disciplinary talent development framework remains underdeveloped. Existing industry professionals predominantly specialize in either AI technologies or low-carbon environmental fields, creating a severe shortage of cross-disciplinary talents with dual competencies in both theoretical knowledge and practical skills. The significant talent gap coupled with prolonged training cycles has become a critical bottleneck hindering the successful implementation of technological convergence.

5.5 Inadequate policy and market systems

Policy support lacks targeted precision, with existing measures predominantly focusing on macro-level guidance rather than specific initiatives like targeted subsidies, tax incentives, or financial support for technological integration, resulting in insufficient motivation for corporate transformation. The absence of unified carbon emission accounting standards and intelligent emission reduction benchmarks, coupled with inadequate industry regulations, creates inconsistent benchmarks for technology integration applications and complicates project validation and performance evaluation. Immature carbon trading markets and green financial systems provide inadequate financing support for smart zero-carbon projects, exacerbating funding shortages for SMEs undergoing transition. Imperfect market promotion mechanisms hinder rapid large-scale implementation of high-quality technological integration outcomes, leading to uneven industry development across sectors.

5.6 Cost Input and Return Imbalance

The integration project combining artificial intelligence and zero-emission technologies requires substantial upfront investment for equipment upgrades, system deployment, algorithm development, and talent acquisition. This entails high initial costs and extended return on investment cycles. Small and medium-sized enterprises (SMEs) often lack sufficient financial resources to cover such significant expenditures. Meanwhile, some large corporations prioritize short-term economic gains over long-term zero-carbon transition initiatives, hindering technological adoption. Additionally, high operational maintenance costs and limited economic returns further diminish corporate participation incentives.

VI. Policy Recommendations for Promoting Deep Integration of Artificial Intelligence and Zero-Emission Technologies

6.1 Tackling Core Technologies to Build a Green and Intelligent Technology System

We will increase R&D investment in core technologies by establishing dedicated research programs focused on key areas including high-end AI chips, low-carbon algorithms, advanced energy storage systems, carbon capture, utilization and storage (CCUS), and hydrogen energy utilization. This initiative aims to foster collaborative innovation among industry, academia, research institutions, and practical applications, overcome technological bottlenecks, and achieve self-reliance and technological sovereignty. Green AI technologies will be vigorously developed through optimized algorithm models and reduced computational energy consumption, with priority given to clean energy-powered data centers and low-carbon computing infrastructure to enable the AI industry's self-driven zero-carbon transition. Technical compatibility research will be strengthened to develop versatile, low-cost integrated solutions that simplify equipment retrofitting while enhancing synergy between AI systems and zero-emission technologies.

6.2 Breaking Down Data Barriers to Build a Secure and Efficient Data System

Accelerate the market-oriented allocation of data elements by establishing cross-industry, cross-departmental, and cross-regional data sharing mechanisms. Develop a unified carbon data monitoring and sharing platform to integrate energy, production, emission, and environmental protection data, breaking down data silos. Improve the data standardization system by unifying standards for carbon emission data accounting, collection, and transmission to enhance data quality and usability. Strengthen data security protection systems by leveraging blockchain and encryption technologies to ensure secure data circulation, while clarifying data ownership, usage, and regulatory rules to balance data sharing with security safeguards.

6.3 Cultivating interdisciplinary talents and strengthening the talent support system

Optimize university discipline structures by introducing interdisciplinary programs in artificial intelligence, big data, energy and environmental protection, and low-carbon engineering. Establish a cross-disciplinary talent development system to cultivate versatile technical and managerial professionals. Enhance corporate employee training through specialized programs in AI and zero-emission technologies to upgrade existing workforce cross-domain competencies. Attract high-caliber international professionals by implementing robust incentive mechanisms with housing, salary, and research support policies to foster talent aggregation. Build industry-academia-research collaboration platforms to facilitate two-way talent mobility between universities, research institutions, and enterprises, thereby strengthening practical expertise acquisition.

6.4 Improve policy safeguards and optimize institutional support environment

Introduce targeted support policies including special subsidies for technology integration, tax incentives, and additional deductions for R&D expenses to reduce corporate transformation costs. Enhance the green finance system by encouraging financial institutions such as banks, insurance companies, and funds to develop financial products like green loans, green bonds, and carbon emission reduction support tools, with a focus on supporting intelligent zero-carbon projects. Standardize industry norms by establishing unified standards for AI zero-emission technology applications, carbon emission accounting, and project acceptance criteria to regulate industry development. Strengthen policy oversight and evaluation mechanisms by incorporating intelligent zero-carbon transition into performance assessment systems for local governments and enterprises, thereby reinforcing emission reduction responsibilities.

6.5 Innovate business models to balance costs and benefits

Promote innovative business models such as energy performance contracting, carbon asset management, and equipment leasing to alleviate upfront investment pressures for enterprises and achieve mutual benefits for all stakeholders. Cultivate specialized service providers offering end-to-end solutions including intelligent zero-carbon transition consulting, customized design, and operation management. Encourage large-scale adoption of technological integration achievements by establishing demonstration projects, industrial parks, and exemplary enterprises, while documenting successful practices to develop replicable models. Unlock economic benefits through energy conservation, carbon trading revenues, and policy subsidies to enhance project ROI and stimulate corporate participation enthusiasm.

6.6 Strengthen international cooperation and incorporate advanced experiences

We will actively engage in global exchanges and cooperation on artificial intelligence and zero-emission technologies, introducing advanced foreign technologies, management expertise, and business models while adapting them to China's national conditions for optimization and upgrading. By strengthening international scientific collaboration, we will jointly tackle core technological challenges and overcome barriers in technology integration. Participating in global carbon governance and digital economy rule-making, we aim to enhance China's influence in green low-carbon development and digital technology sectors. Furthermore, we will promote the global dissemination of technological integration achievements to support the realization of global carbon neutrality goals.

VII. Conclusion and Prospects

7.1 Research Conclusions

Against the backdrop of rapid digital economy development and accelerated global carbon neutrality efforts, the deep integration of artificial intelligence and zero-emission technologies has become an essential approach to driving green socioeconomic transformation, addressing energy and environmental challenges, and achieving high-quality sustainable development. By leveraging data as the foundation, intelligence as the core, and zero-carbon as the ultimate goal, these technologies form a closed-loop operational system with unique advantages including precise emission reduction, dynamic regulation, holistic optimization, and cost-efficiency enhancement. They demonstrate extensive application potential across energy systems, industrial sectors, construction industries, transportation networks, and ecological governance initiatives.

While technological integration has achieved initial progress, it still faces practical challenges including AI energy consumption conflicts, technical barriers, data silos, talent shortages, inadequate policies, and cost imbalances, which constrain both the depth of integration and its adoption speed. To drive deeper and more substantial technological convergence, comprehensive efforts must be made across multiple dimensions: tackling technical bottlenecks, promoting data sharing, cultivating talent pools, strengthening policy support, innovating business models, and fostering international collaboration. By establishing a multi-tiered support system, we can overcome developmental hurdles and unlock the full potential of integration dividends.

7.2 Future Outlook

With continuous advancements in digital technologies and zero-carbon solutions, the integration of artificial intelligence and emission-reduction technologies is evolving into deeper synergies across broader domains, demonstrating trends of comprehensive coverage, end-to-end coordination, autonomous intelligence, and sustainable low-carbon development. In the future, intelligent zero-carbon technologies will permeate every aspect of economic and social systems, achieving zero emissions throughout production and daily life processes. Green AI and low-carbon computing power will become mainstream solutions, effectively addressing AI's inherent energy consumption challenges. Free data flow will enable more robust cross-sector integration ecosystems, while abundant interdisciplinary talent and well-established policy-market frameworks will solidify technological convergence as the core driver of zero-carbon transition.

China should firmly seize the strategic opportunity of the overlap between the digital economy and green transformation, continuously promote the deep integration of artificial intelligence and zero-emission technologies, accelerate the green upgrading of industries, build a clean, low-carbon, safe, and efficient modern economic system, contribute to achieving the "dual carbon" goals, and provide China's wisdom and strength for global ecological environmental protection and sustainable development.

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