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Determinants of Non-Hydro Renewable Energy Consumption in China's Provincial Regions

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Abstract: This study investigates the determinants of non-hydro renewable energy (NHRE) consumption across 31 provincial regions in China, spanning from 2015 to 2022. Utilizing fixed effects and moderating effects, the research analyzes the impacts of research and development intensity (RDI), urbanization (UR), and human capital (HC) on NHRE consumption (NHREC). Additionally, the moderating roles of industrial structure (IS) and tax (TA) are examined, along with control variables such as informationization and economic development. The findings reveal that increased RDI significantly boosts NHREC by enhancing technological advancements. UR also positively affects NHREC, particularly in rapidly urbanizing regions, while HC provides a skilled workforce that drives renewable energy projects. However, the study identifies that concentrated industrial structures and high taxes can negatively moderate these positive impacts, highlighting the complex interplay of these factors. Policy recommendations include creating "Renewable Energy Innovation Hubs" in underdeveloped regions to attract startups and researchers, developing "Solar Cities" with mandated solar panels on all buildings, and introducing a "Carbon Offset Lottery" to incentivize investments in renewable energy.

Keywords: non-hydro renewable energy; research and development intensity; urbanization; human capital; industrial structure; tax; regional disparities

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1. Introduction

The determinants of non-hydro renewable energy (NHRE) consumption are critically important on a global scale, offering key insights into the factors influencing the adoption and use of sustainable energy resources worldwide. A deep understanding of these determinants is crucial for formulating strategies to mitigate climate change, aligning with global initiatives such as the Paris Agreement. They play a significant role in enhancing energy security by reducing reliance on fossil fuels, which is vital for economic resilience. The promotion of non-hydro renewables is instrumental in supporting sustainable development by mitigating environmental degradation and improving public health outcomes. The renewable energy sector holds substantial potential for economic growth and job creation. Understanding these determinants is essential for fostering environments conducive to technological innovation and investment in research and development. Effective policy formulation, based on a thorough analysis of legal and regulatory frameworks, is crucial for scaling up the use of renewable energy. Moreover, identifying environmental factors that affect renewable energy consumption is critical for developing strategies to protect ecosystems while meeting energy needs [1–5].

Diniz and Couto [6] highlight that since 2002, Brazil has seen a more than 22-fold increase in installed wind power capacity, a key component of NHRE, facilitated by successful energy supply programs and a renewable-oriented financial framework. This expansion significantly contributes to the country's renewable energy development. Yu et al. [7] investigated the impact of climate change on the investment efficiency of 205 listed NHRE firms in China. The study found that CO_2 emissions and extreme weather events significantly improved investment efficiency, while extreme temperatures had a negative impact. It also noted that in low-marketized environments and state-owned enterprises, the combined effects of climate change and renewable energy policies more markedly enhanced the investment efficiency of wind and solar firms. According to Zhou et al. [8], in an optimal power generation structure, clean energy can replace fossil fuel generation, with renewable energy expected to account for over 42% of total power generation by 2040. The annual growth rate for NHRE is projected at 12.06%, with solar photovoltaic showing the highest growth at 17.95%. Trotter [9] report that while international agencies like IRENA and the IEA forecast a rapid increase in NHRE in Africa, reaching 25–40% by 2030, data-driven machine learning models predict that the share might remain below 10%. Seriño [10] explores the factors influencing the diversification of NHRE sources over 30 years in 117 developing countries, using a new diversification measure and various estimation techniques. After accounting for regional differences, the study concludes that higher per capita income, implementation of renewable energy policies, technological innovations, and improvements in human capital all encourage diversification.

NHRE includes renewable energy sources other than hydropower, derived from natural processes that are naturally replenished on a human timescale. NHRE comprises various forms of energy such as solar, wind, biomass, geothermal, marine, and hydrogen energy. Solar energy is harnessed using photovoltaic panels and solar thermal systems to convert sunlight into electrical or thermal energy. Wind energy captures kinetic energy from wind through turbines to generate electricity. Biomass energy utilizes organic materials like crop residues and animal manure to produce energy. Geothermal energy exploits the Earth's internal heat for heating and power generation. Marine energy includes tidal, wave, and ocean thermal energy, which are harnessed to generate electricity. Fuel cells and hydrogen technologies involve the use of hydrogen, which can be produced through renewable processes, and its role in NHRE is contingent on the sustainability of its production methods.

The importance of NHRE compared to broader "Renewable Energy" lies in its specific advantages and characteristics. NHRE, encompassing solar, wind, geothermal, biomass, and marine energy, provides a diverse array of resources that can be tailored to different regional conditions. NHRE projects often have a smaller environmental impact compared to hydropower, which can cause significant ecological disruptions. The diversification into NHRE enhances energy security and contributes to system stability. Recent technological advancements and cost reductions have made NHRE, especially solar and wind energy, more economically viable and attractive under various policy incentives.

Developing NHRE necessitates specialized policy and legal frameworks that address issues such as land use, grid access, subsidies, and market entry. This focus allows for the creation of detailed strategies to tackle the challenges associated with energy transition, thereby supporting sustainable development goals. Varga et al. [11] assert that photovoltaic power generation has become increasingly significant in the context of global sustainability goals, particularly in the rapid decarbonization of the energy sector and the consideration of geopolitical energy security issues. As the most widely deployed form of non-hydro renewable energy, photovoltaic technology plays a crucial role in this transition. Handayani et al. [12] examined the potential for integrating 100% renewable energy in Cambodia, Laos, and Myanmar through the exploitation of hydropower resources and the deployment of non-hydro renewable energy sources. Their study emphasizes the necessity of developing 16.1 GW of energy storage systems by 2050 to manage the variability of renewable energy sources effectively. Sanchez et al. [13] advocate for the use of non-hydro renewable energy and modern technologies as alternatives to traditional biomass, such as fuelwood, to significantly reduce water consumption while meeting Africa's growing energy demands.

China's commitment to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060 highlights the critical need for a transition to cleaner energy sources. Zhou et al. [8] and Zhou et al. [14] articulate these targets as pivotal components of China's environmental strategy, which necessitates an in-depth understanding of the role of policy mechanisms in influencing renewable energy consumption. The design of effective energy policies is essential for harmonizing economic growth with the objectives of sustainable development. Marques et al. [3] emphasize the significance of well-crafted policies in fostering the adoption of renewable energy, thereby requiring a comprehensive analysis of the policy instruments that drive the adoption of non-hydro renewable energy sources.

Green finance is essential in promoting the development of NHRE. Ma et al. [4] emphasize the importance of economic incentives and mechanisms in facilitating the transition to renewable energy through green finance initiatives. These initiatives lower financing costs and bolster technological research, making them critical to accelerating the adoption of renewable energy sources. Electricity is a cornerstone of economic development and societal well-being. Asadi et al. [15] highlight the economic advantages of transitioning to renewable energy, which not only supports economic growth but also enhances public welfare. Dukpa [16] discuss Bhutan's goal to achieve 20 MW of NHRE capacity by 2025, noting the current absence of a pricing policy to support this target. The study recommends the introduction of a feed-in tariff system tailored to different customer categories to promote NHRE development. Chen et al. [17] argue that achieving climate targets necessitates a shift from bilateral financing of fossil fuels to funding renewable technologies, which is crucial for reducing global carbon emissions. Kim and Lee [18] review the World Bank's energy project investments from 1985 to 2019, revealing an increase in NHRE investments from 1% (1985–1990) to 16.5% (2011–2019), while commitments to fossil fuels persist.

The increasing public awareness of climate change and its repercussions is a critical sociocultural factor propelling the adoption of renewable energy. This urgency to address climate change, underscored by Liu & Feng [19] and Yi et al. [20], reflects the mounting societal pressure to embrace sustainable practices. The transition from thermal to renewable energy sources is vital for mitigating carbon emissions. Lin & Shi [21] and Liu & Feng [19] emphasize the pivotal role of technological advancements and innovations in enabling this shift.

Establishing effective legal frameworks is crucial for promoting the deployment of renewable energy. Olanrele and Fuinhas [22] recommend that Sub-Saharan African countries activate renewable energy support mechanisms, strengthen legal and institutional frameworks, and alleviate bottlenecks and bureaucratic challenges associated with renewable electricity investments to increase the utilization of NHRE. Wang et al. [23] discuss the necessity for fair and efficient allocation of renewable portfolio standards (RPSs) to encourage renewable energy consumption. Zhao et al. [5] underscore the critical link between water resources and NHRE, stressing environmental considerations in deploying these technologies, particularly in light of China's water conservation needs. Developing countries, including China, play a substantial role in global carbon emissions. Pfeiffer & Mulder [1] emphasize the environmental necessity of transitioning to renewable energy to mitigate these emissions.

The motivation for this study stems from the recognition that NHREC in China is influenced by a complex interplay of political commitments, economic incentives, societal attitudes, technological advancements, legal frameworks, and environmental imperatives [24–26]. Understanding these determinants is essential for developing effective strategies to tackle global environmental challenges, enhance energy security, and support China's sustainable development goals. This research employs a PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) analysis to thoroughly examine the drivers behind renewable energy adoption in various Chinese provincial regions, thereby informing policy formulation and implementation aimed at increasing renewable energy consumption.

The primary objective of this study is to mitigate global climate change and address China's significant carbon emissions by analyzing the main factors influencing NHREC. This research aligns with international initiatives such as the Paris Agreement and seeks to support China's sustainable development objectives by promoting NHRE, reducing dependency on fossil fuels, strengthening energy security, and improving public health outcomes. By understanding the factors that drive NHREC, this study aims to foster economic growth, job creation, and technological innovation and attract investment. Effective policy design, particularly in the realm of Renewable Portfolio Standards, is crucial for achieving these goals. The study also investigates regional disparities in NHREC across Chinese provinces, providing empirical evidence to inform precise policy formulation.

This study investigates the determinants of NHREC across 31 provincial regions in China from 2015 to 2022. By employing a fixed effects and moderating effects model, we analyze the impacts of research and development intensity (RDI), urbanization (UR), and human capital (HC) on NHREC. Additionally, the moderating roles of industrial structure (IS) and tax (TA) are examined, along with control variables such as informationization and economic development. The primary purpose of this study is to identify and quantify the key determinants of NHREC in China, with a specific focus on regional disparities. By understanding these determinants, the study seeks to inform policymaking and strategic initiatives aimed at promoting renewable energy consumption and achieving carbon neutrality goals. According to Tian et al. [24], China possesses sufficient wind and solar technological potential to support its vision of achieving carbon neutrality by 2060. However, these resources are unevenly distributed, predominantly concentrated in the western and northern regions, particularly in Xinjiang and Inner Mongolia, which together account for over 76% of the total technical potential for onshore wind and solar energy.

This study makes several unique contributions to the existing body of literature on NHREC: (1) The study develops a systematic analytical framework that considers direct factors such as RDI, UR, and HC, while also examining industrial structure and tax as moderating variables, alongside various control variables. (2) The study employs fixed effect and moderating effect models, confirmed appropriate by the Hausman test, addressing issues of endogeneity and improving accuracy. Interaction terms are used to uncover complex relationships between core explanatory and moderating variables, offering new insights into the mechanisms of influence. (3) The research reveals significant regional differences in the factors affecting NHREC across Chinese provinces, providing critical information for the formulation of region-specific policies and differentiated management strategies considering local characteristics and actual needs. (4) The empirical analysis offers a strong evidence base for policymakers, suggesting optimizing financial systems, adjusting industrial structures, and alleviating tax burdens to stimulate NHRE development. The findings support the design of targeted policies to enhance NHREC. (5) The study combines theoretical insights with empirical findings, validating hypotheses from the existing literature and offering new perspectives on the roles of research and development intensity, urbanization, and human capital in promoting NHREC. This integrated approach provides a holistic understanding of the determinants of NHREC. (6) By adopting a global perspective while focusing on local action, the research offers valuable experiences and strategies for promoting renewable energy consumption and addressing climate change. The study's findings are particularly relevant in the context of global sustainable development goals and international climate agreements, such as the Paris Agreement.

This research investigates the determinants of non-hydro renewable energy (NHRE) consumption to provide strategic insights for advancing sustainable energy transitions in China and globally. The structure of the article, aside from the introduction, includes the following sections: Literature Review and Theoretical Background: analyzes factors affecting NHREC, including energy diversity, infrastructure, geography, power transmission, and policy frameworks, providing a theoretical foundation for NHRE adoption. Research Design: describes data collection from 31 Chinese provinces (2015–2022) using statistical sources. The study employs fixed and moderating effect models, focusing on variables influencing NHREC. Results and Analysis: presents the impact of various factors on NHREC, highlighting regional differences and the specific influence of different variables. Mechanism Analysis and Discussions: examines the internal mechanisms among variables through methods such as moderation effects, path analysis, and causal diagrams, emphasizing the importance of policy interventions and optimized energy policies for sustainable development. Conclusions and Policy Implications: summarizes key findings, contributions, and future research directions, emphasizing the need to advance NHRE development to achieve China's carbon neutrality goals by 2060.

2. Literature Review and Theoretical Background

The significance of NHRE is highlighted by its global milestones [27–32]. (see Figure 1) Gonzalez-Salazar and Poganietz [33] emphasize the complementary nature of solar, wind, and hydro power, which enhances the reliability and resilience of regional energy systems. They suggest that Latin America could stabilize its energy system by developing complementary wind and solar resources, thus reducing dependence on a single energy source and improving adaptability to climate events. Kudelin and Kutcherov [34] identify key factors influencing wind energy development in Russia, including investor support schemes, licensing processes, societal and educational issues, availability of wind resource data, local manufacturing capabilities, and supportive policies. These factors play a critical role in the growth of wind energy, one of the leading NHRE sources globally. Marques et al. [3] analyze the effects of energy policies on the installed capacity and electricity production of wind, solar photovoltaic, and non-hydro renewables in global, European, and OECD countries. The findings indicate that policy instruments have varied impacts over the short and long term. Most policy tools are directly linked to public budgets, which may impose excessive economic burdens. In contrast, market-based tools only promote renewable energy in the long term, as they are effective when renewable technologies are mature and well-integrated into the electricity market. Market-based instruments are not effective in the early diffusion of renewable technologies.

The 1970s oil crisis catalyzed significant investments in alternative energy sources, leading to the establishment of the first commercial wind farms in California by the 1980s. This marked the beginning of large-scale wind energy deployment. Germany's Renewable Energy Sources Act in the 1990s provided substantial incentives for solar and wind energy, significantly boosting global investments in these technologies. The European Union's Renewable Energy Directive in the 2000s set binding targets that further propelled the growth of NHRE. The Paris Agreement of 2015 continued this momentum, spurring investments in NHRE, particularly as solar and wind energy costs rapidly declined and installations increased.

By 2018, global renewable energy capacity had reached 1650 GW, largely supported by advancements in solar and wind technologies. Despite the COVID-19 pandemic in 2020, the sector experienced record growth, especially in solar and wind. The U.S. Inflation Reduction Act of 2021 introduced significant funding for renewable energy projects, while China added 160 GW of capacity in 2022, accounting for nearly half of the global total, driven by its 14th Five-Year Plan. The European Union also significantly increased its deployment of solar PV and wind by over 50 GW.

By 2023, global renewable energy capacity had expanded by 50%, reaching 510 GW, with China leading the growth. Projections for 2024 indicate that wind and solar PV will surpass hydropower in electricity generation. Renewables are expected to outpace coal by 2025, with a global capacity target of 7300 GW by 2028, driven by supportive policies in over 130 countries. These developments underscore the critical role of NHRE in the global energy transition, highlighting the need for continued policy support and technological innovation to meet climate goals. Lin and Shi [21] project that by 2025, thermal, hydro, nuclear, and non-hydro renewable power will account for 60.46%, 20.43%, 6.43%, and 12.68% of the energy mix, respectively. Pfeiffer and Mulder [1] argue that a diverse energy mix enhances the likelihood of NHRE adoption, suggesting that the composition of the energy mix serves as a moderating variable in this adoption process.

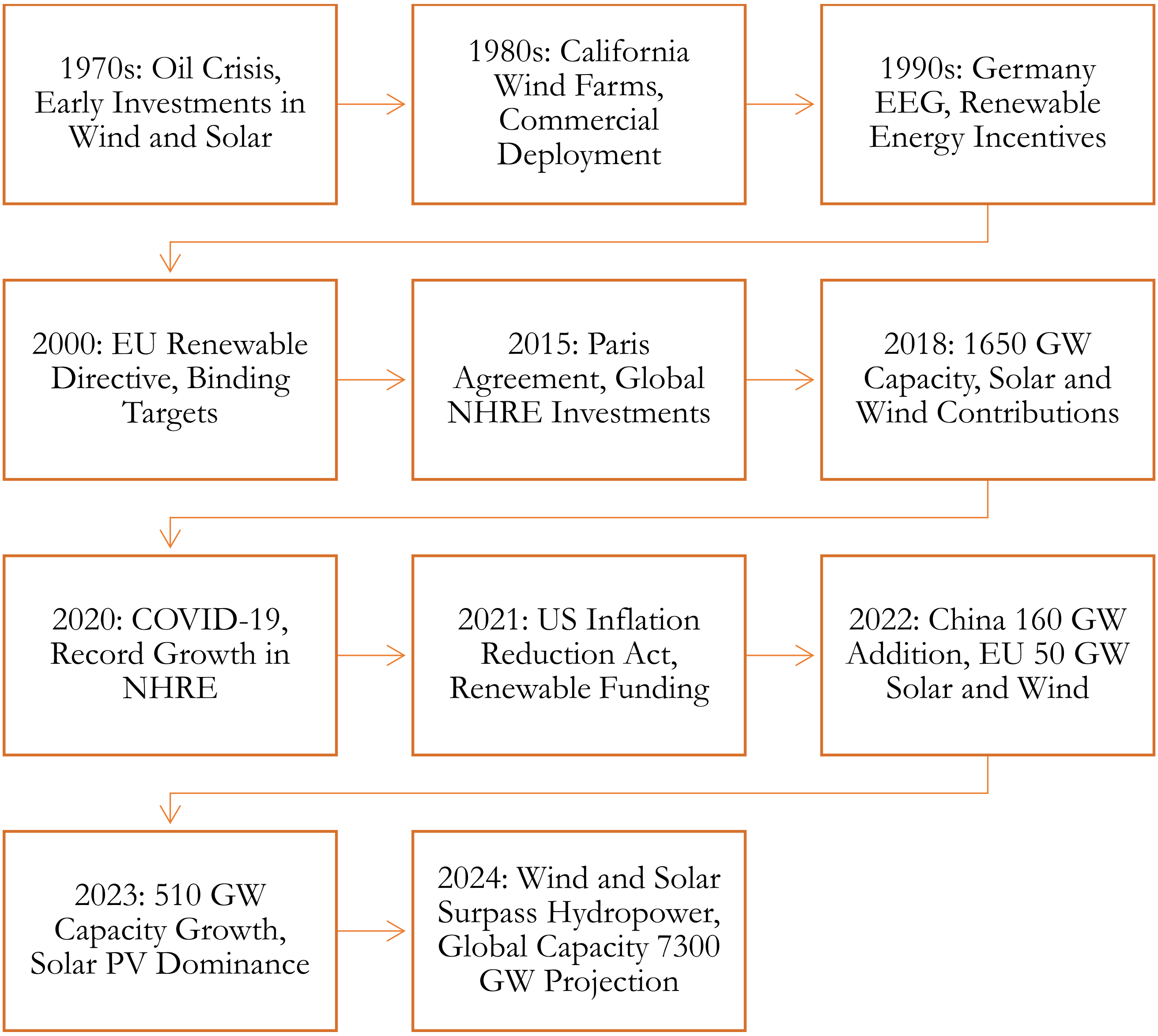


Figure 1. Significant events in the history of NHRE.

The development of non-hydro renewable energy (NHRE) in China has been marked by key milestones, demonstrating its essential role in the nation's energy transition and climate goals (see Figure 2) [20,23,35–37]. According to Wang et al. [38], China's hydropower generation experienced significant growth in 1978 and 2008, while non-hydro renewable energy generation saw a notable increase in 2005. These shifts indicate the impact of recent regulatory shocks and policy changes.

The 2006 enactment of the Renewable Energy Law provided a legal framework to promote renewable energy development. The Mid- to Long-term Plan for Renewable Energy Development, issued in 2007, set ambitious targets for NHRE sources, including wind and solar. The 12th Five-Year Plan (2011–2015) significantly raised solar installation targets, leading to rapid capacity expansion. China's 2015 commitment to peak carbon emissions by 2030 and achieve carbon neutrality by 2060, as outlined in the Paris Agreement, highlighted the critical importance of NHRE in achieving these objectives. The 13th Five-Year Plan (2016–2020) established specific targets for wind and solar energy, focusing on integrating these technologies rather than merely expanding capacity. Amendments to the Renewable Energy Law in 2018 mandated the full purchase of renewable energy and established provincial dispatch quotas to ensure efficient NHRE utilization. The National Development and Reform Commission's market-oriented reforms in 2019 further strengthened the NHRE sector through renewable electricity consumption obligations and green power trading mechanisms.

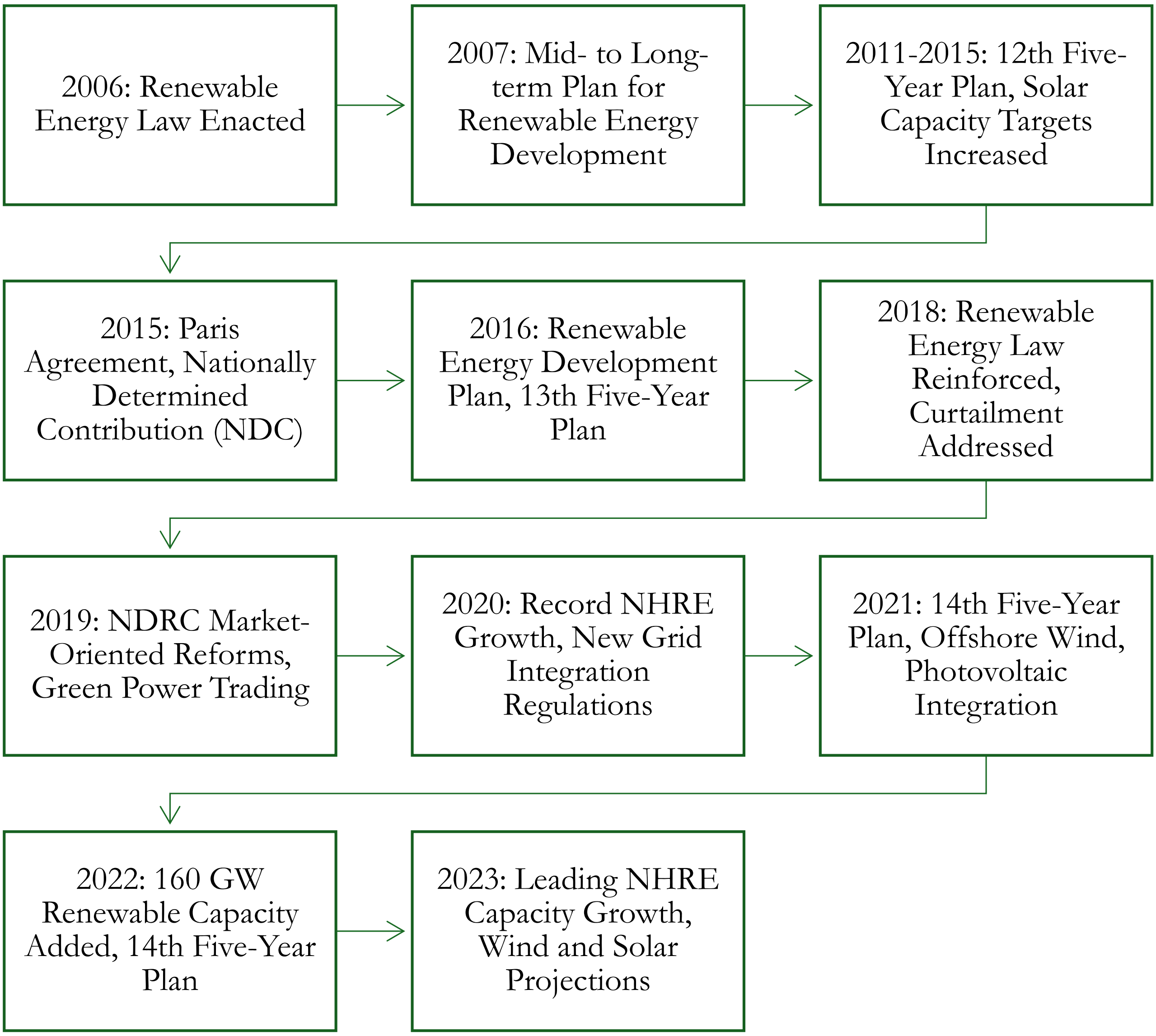


Figure 2. Significant events in the history of China's NHRE.

The year 2020, despite the global pandemic, saw unprecedented growth in NHRE installations. This surge was driven by new regulatory frameworks that facilitated greater integration of renewable energy into the national grid and reduced dependency on coal power. The 14th Five-Year Plan (2021–2025) set forth ambitious targets for renewable energy expansion, particularly emphasizing the development of offshore wind projects and the integration of photovoltaic power with other sectors. In 2022, China added 160 GW of renewable capacity, largely in line with these strategic goals. By 2023, China led globally in NHRE capacity growth, with projections indicating that wind and solar PV will surpass hydropower in electricity generation by 2024. These developments underscore China's commitment to NHRE as a cornerstone of its energy strategy, highlighting the crucial role of continuous policy support and technological innovation in achieving its long-term climate objectives.

2.1. Factors Influencing Non-Hydro Renewable Energy Consumption

The examination of NHREC in China explores various economic factors and theoretical foundations. The impact of RDI is highlighted as crucial for fostering technological innovation, which is a key driver of long-term economic growth. Lin and Shi [21] emphasize the shift from a reliance on thermal power to renewable energy, attributing this transition to continuous technological advancements. This aligns with neoclassical growth theories, which link productivity improvements to technological progress. Technological advancements enhance the maturity and economic viability of NHRE technologies, lowering costs and increasing market competitiveness.

UR plays a significant role in shaping energy consumption patterns by modernizing infrastructure and increasing the demand for clean energy. Liu and Feng [19] discuss the importance of fossil fuel alternatives in addressing global warming and energy crises, suggesting that urbanization indirectly promotes NHREC by raising the demand for efficient and sustainable energy sources. As urban areas expand and incomes rise, there is a growing demand for NHRE, further encouraging its adoption.

HC is also critical, as it influences NHRE through the lens of human capital theory, which posits that education and skill enhancement are vital for economic development. Higher levels of human capital facilitate technological innovation and industrial upgrading, which in turn support the adoption of NHRE technologies. Ma et al. [39] stress the importance of building innovation systems and attracting skilled talent to drive NHRE development, underscoring the role of an educated and skilled workforce in advancing these technologies.

Several key variables significantly impact NHREC. Financial development improves capital market efficiency and reduces financing costs, thus promoting NHRE investment. Ma et al. [39] highlight the role of green finance in the growth of the NHRE industry, which aligns with theories suggesting that financial deepening incentivizes investment by lowering borrowing costs and expanding funding channels (Dialogue Earth) (International). The transformation of the industrial structure is crucial for altering energy consumption patterns, with shifts toward less carbon-intensive industries increasing the NHRE share. Lin and Omoju [40] demonstrate that such economic restructuring aims to reduce dependency on traditional energy sources and promote green energy transitions. The tax affects NHRE by influencing cost structures and investment decisions; lower taxes enhance profitability, encouraging investment in initially high-cost renewable energy projects. This aligns with public economics principles, where tax incentives are used to stimulate sector-specific growth. The degree of openness impacts a nation’s engagement in international energy markets and technology transfers, with trade liberalization and foreign direct investment facilitating the dissemination and application of advanced NHRE technologies. However, Ma et al. [39] note that foreign direct investment has a negative impact on NHRE in developed countries, highlighting the complex dynamics of international economic interactions and market competition.

Understanding the economic factors and their theoretical foundations is essential for formulating policies and strategies to promote NHRE. Financial development, including the growth of stock markets and bank intermediaries, is a significant driver of NHRE expansion in both developing and developed nations, as demonstrated by Ma et al. [39]. Foreign direct investment has a dual impact, fostering NHRE growth in developing countries while impeding it in developed ones. Xu et al. [41] discuss the strategic reallocation of policy costs to optimize the consumption of renewable electricity. Zhao et al. [5] investigate the elasticity of NHRE availability in relation to industrial output, highlighting the sector’s sensitivity to energy resource variations. Yi et al. [20] underscores the importance of geographic distribution in the placement of renewable energy facilities, which impacts regional energy security and efficiency. Asadi et al. [15] provides modeling scenarios for NHRE-based electricity supply, offering insights into potential future energy systems. The role of economic and regulatory instruments in accelerating the diffusion of NHRE technologies is highlighted by Pfeiffer and Mulder [1], who emphasize the need for supportive policies and market frameworks. Wang et al. [23] compare the efficiency and equity of RPSs target allocations, providing a critical analysis of policy effectiveness. Additionally, Lin and Omoju [40] and Olanrele and Fuinhas [22] explore the impacts of financial development and FDI on the adoption of renewable electricity, suggesting that these factors are crucial for the scaling of NHRE infrastructure.

2.2. Impacts of Research and Development Intensity, Urbanization, and Human Capital on Non-Hydro Renewable Energy

The impact of R&D intensity on NHRE is pivotal in shifting to a sustainable energy mix. According to Schumpeter's theory of creative destruction, economic growth and structural change are driven by innovation and technological progress. In renewable energy, R&D leads to technological advancements that enhance the efficiency and cost-effectiveness of NHRE sources, making them more competitive with fossil fuels. The learning curve effect also plays a significant role, suggesting that production costs decline as cumulative experience increases. This process is accelerated by heightened R&D intensity, reducing costs for technologies like solar panels and wind turbines. Empirical studies, such as Ma et al. [4], highlight green finance's role in fostering NHRE development, supporting R&D activities that drive technological innovations. Lin and Shi [21] note that while hydropower benefits from EHV and UHV projects, these projects do not significantly promote NHREC, indicating the need for targeted strategies. Green finance, as discussed by Ma et al. [39], reduces industry financing costs and enhances R&D investment, facilitating increased NHRE generation, as highlighted by Lin and Omoju [40].

Urbanization significantly impacts NHREC through various economic and social mechanisms. Theoretically, urbanization increases overall energy demand due to population concentration and rising living standards. Cities, driven by sustainable development goals, transition to cleaner energy sources to mitigate pollution and meet climate targets, thus boosting NHRE demand. Urban areas, equipped with advanced infrastructure like smart grids and energy storage systems, support the integration of renewable energy. Economic development associated with urbanization provides financial resources and incentives for renewable energy investments, supported by policies like feed-in tariffs and tax credits. The shift toward a more service-oriented and less energy-intensive industrial structure in urban economies promotes cleaner energy sources. Empirical studies support these insights, with Lin and Omoju [40] noting that economic development enhances NHRE size, although its share in total electricity generation may vary. Olanrele and Fuinhas [22] emphasize urbanization's positive impact on NHRE and the need for targeted policies addressing regional differences and infrastructure development. Ma et al. [39] suggest that urbanization supports industrial upgrading, indirectly contributing to renewable energy consumption. Diniz and Couto [6] highlight that wind energy investments in Brazil's northeast not only increased renewable energy supply but also created jobs and boosted regional economic development, particularly in underdeveloped areas.

The relationship between human capital and NHRE is deeply rooted in principles of economic development and innovation theory. Human capital, encompassing the skills, knowledge, and experience of individuals, is essential for adopting and expanding NHRE sources. It drives technological innovation, facilitating the development and diffusion of renewable energy technologies. A skilled workforce contributes to R&D, improves process efficiency, and aids in the commercialization of advanced renewable energy solutions, thereby boosting NHRE. Investments in human capital led to sustained economic growth, with productivity gains allowing societies to allocate more resources toward environmentally friendly technologies, including NHRE. This creates a positive feedback loop where higher NHRE further promotes economic development and human capital enhancement. Education raises awareness about environmental issues and fosters a culture that values sustainability, translating into greater support for renewable energy policies and personal choices favoring clean energy consumption.

Ma et al. [39] emphasize the need for policymakers to build a technological innovation system for the NHRE industry and attract high-level talent, highlighting the importance of human capital in advancing renewable energy development. Pfeiffer and Mulder [1] note that higher per capita income and education levels accelerate the diffusion of NHRE, aligning with the understanding that a more educated workforce and prosperous society are more likely to adopt and invest in renewable energy technologies. Lin and Omoju [40] also acknowledge that financial development, often facilitated by a skilled workforce, positively impacts the share of NHRE generation.

2.3. The Role of Moderating and Control Variables

Analyzing NHREC necessitates understanding the roles of moderating and control variables, which impact the integration and spread of NHRE through various economic theories and mechanisms. India's National Solar Mission aims for 175 GW of non-hydro renewable energy capacity by 2022, highlighting the prioritization of renewable energy for achieving a techno-economic balance and generating positive environmental impacts [42]. Gao et al. [26] highlight that policy adjustments and market changes significantly impact the development and performance of technologies like direct methanol fuel cells. They suggest optimizing China's renewable energy portfolio standards to promote low-carbon technologies.

Industrial structure (IS) affects energy demand profiles, with heavy industry regions relying more on fossil fuels, while service and technology-driven economies adopt energy-efficient practices and renewable energy more readily. Tax (TA) influences the financial environment for renewable investments, with high taxes restricting capital availability and tax incentives enhancing NHRE investments. Risk management practices in financial institutions can also impede funding for industrial R&D [38]. The heterogeneity test by Ma et al. [4] shows that green finance impacts vary across regions, indicating the contextual role of these factors. Zhao et al. [5] identify infrastructure development and geographical location as significant moderating factors.

Informationization (IN) enhances energy management systems, facilitating NHRE integration. Economic development (ED) indicates a region's capacity to adopt sustainable energy solutions, with wealthier economies more inclined toward NHRE technologies (Dialogue Earth and SpringerLink). Ma et al. [39] suggest regions with lower environmental quality by 2025 will have a lower NHRE proportion.

Labor (LA) is vital for NHRE sector evolution, requiring a skilled workforce for installation, maintenance, and innovation. Fiscal support intensity (FSI), including subsidies and tax exemptions, reduces initial costs and encourages private sector involvement. Transportation infrastructure (TI) ensures logistical feasibility for renewable energy projects, with robust networks vital for shaping distributed energy systems, as emphasized by the Global Energy Policy Center and other sources. Yi et al. [20] note that inter-regional transmission enhances system efficiency by reducing start-up costs.

Openness (OP) facilitates access to external financing, technological advancements, and new markets, accelerating NHRE technology adoption [14,39]. Legislative frameworks and policy adjustments are crucial, with energy laws more effective in countries with strong legal systems [19]. Wang et al. [38] and Xu et al. [41] highlight the impact of policy adjustments and scenarios on renewable energy targets and market competition.

Governmental and Institutional Frameworks: strengthening legal and institutional frameworks can reduce bottlenecks and bureaucracies associated with renewable electricity investments [22]. Wang et al. [23] suggest adopting national renewable energy certificate trade markets to reduce costs and maintain equity, providing relevant policy suggestions.

This section critically analyzes the limitations and gaps in existing studies on NHREC. The primary shortcomings identified include the lack of comprehensive regional analyses addressing significant disparities in NHREC across different regions within China, insufficient consideration of the moderating effects of economic structures and fiscal policies, such as IS and TA, on the relationship between key determinants and NHRE consumption, and the limited integration of both technological and socio-economic factors in analyzing NHRE adoption, often focusing on either technological innovation or socio-economic conditions in isolation.

This study addresses these gaps by providing an in-depth regional analysis, examining disparities in NHREC across eastern, central, western, and northeastern regions of China. This regional focus allows for the development of targeted policies that cater to specific local conditions and needs. Additionally, the study analyzes the moderating roles of IS and TA, offering deeper insights into how these economic structures and fiscal policies influence the relationship between RDI, UR, HC, and NHREC. This approach provides a nuanced understanding of the complex interactions between these variables. By incorporating both technological factors (RDI) and socio-economic factors (UR, HC, IS, and TA), the study presents a holistic view of the determinants of NHRE consumption. This integrated approach facilitates a comprehensive understanding of the multifaceted drivers of renewable energy adoption, leading to more thorough analysis and policy recommendations.

3. Research Design

This study employs panel data from 31 provincial regions in China, spanning from 2015 to 2022, with data sourced from the National Bureau of Statistics of China, China Statistical Yearbook, China Energy Statistical Yearbook, and various provincial statistical reports. These sources provide comprehensive and reliable data on key variables [43–51].

The variables selected include RDI, UR, HC, IS, and TA. RDI represents technological innovation, UR captures the effects of urban development, HC reflects the availability of skilled labor, IS indicates the economic structure, and TA represents fiscal policies. The sample selection is based on the diversity and representativeness of these regions in terms of economic development, urbanization, industrial structure, and renewable energy potential, providing a robust basis for analyzing regional disparities and the factors influencing NHRE consumption.

This study categorizes variables into dependent, core explanatory, moderating, and control variables. The dependent variable, NHREC, represents the consumption of non-hydro renewable energy power, expressed logarithmically. Key explanatory variables include RDI, indicating the ratio of internal R&D expenditure to regional GDP, reflecting innovation investment. UR is gauged by the urban population's share of the total population, assessing urbanization's influence on NHREC. HC is measured by the ratio of higher education students to the total population, highlighting education's role in NHRE adoption.

Moderating variables include IS, defined as the ratio of tertiary to secondary industry output, indicating the economic composition's impact on NHREC. TA is the ratio of tax revenue to regional GDP, reflecting financial incentives or constraints on NHRE investments.

Control variables provide a baseline for analyzing NHREC. IN measures the integration of information technology in energy management through the ratio of total postal and telecommunications business to regional GDP. ED, represented by the logarithm of per capita GDP, indicates economic prosperity and NHRE support capacity. LA, expressed as the logarithm of the number of employed individuals, denotes human resources for NHRE development. FSI is the ratio of general budgetary expenditure to regional GDP, indicating government financial support for NHRE projects. TI, measured by the logarithm of total freight volume, reflects the infrastructure capability for NHRE logistics. OP is the ratio of total import and export value to regional GDP, indicating the impact of international trade on NHRE technology and investment.

The empirical process is visually represented in Figure 3, outlining the methodological steps taken in the analysis. The data utilized in this study were sourced from authoritative and reliable official reports, ensuring the accuracy and credibility of the findings. To mitigate potential biases and eliminate dimensional disparities, logarithmic transformations were applied to select variables. The centralization of moderating variables was performed to reduce multicollinearity and enhance model fit.

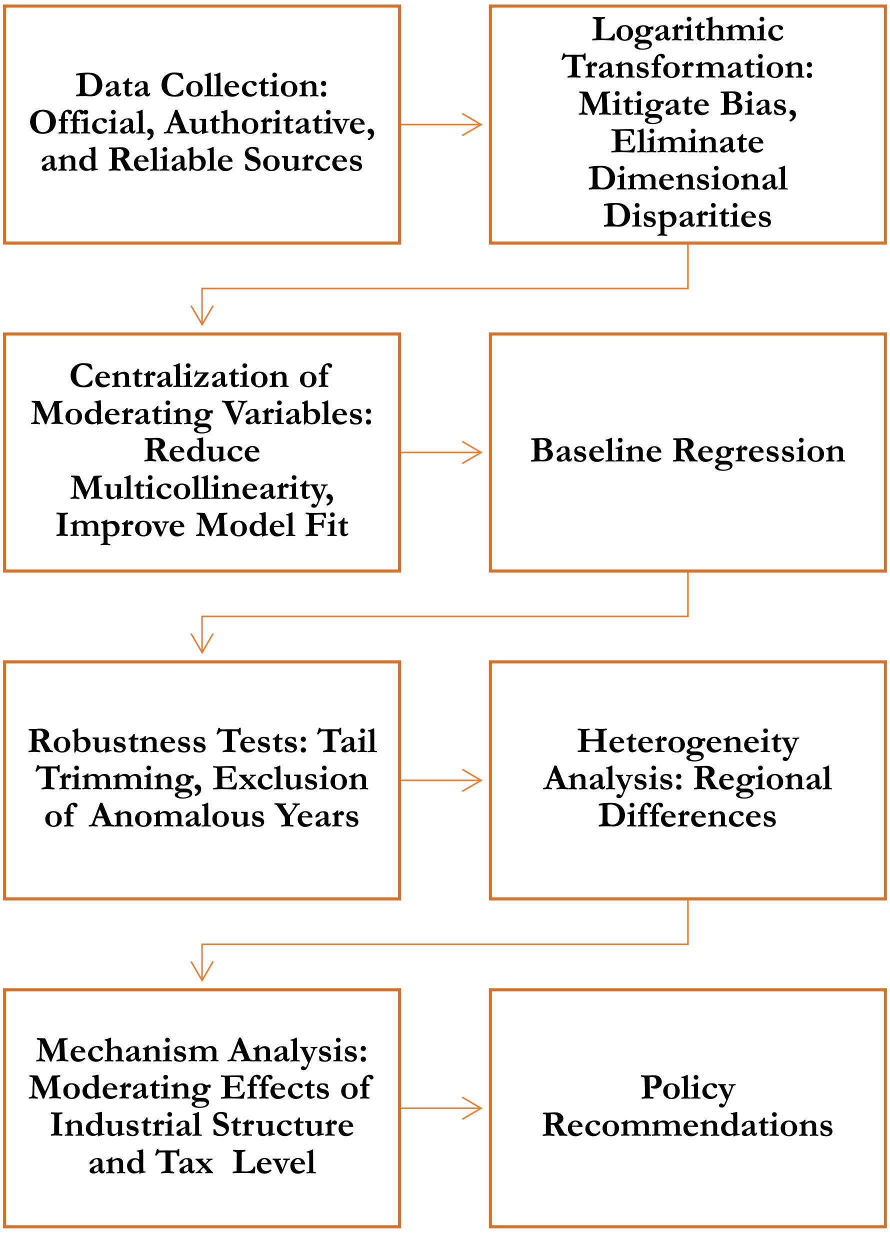


Figure 3. Empirical process.

The panel data regression model is widely utilized in econometrics due to its ability to integrate information from both time series and cross-sectional data, providing a more comprehensive dynamic analysis of economic phenomena. There are two primary types of panel data regression models: the fixed effects model and the random effects model. The fixed effects model (FEM) assumes that individual effects are time-invariant, meaning each entity has its unique constant term representing its specific characteristics. These characteristics, though unobservable, significantly influence the dependent variable. The FEM eliminates the impact of these individual-specific traits on the estimation results by introducing a unique intercept for each entity.

Conversely, the random effects model (REM) assumes that individual effects are random and uncorrelated with the explanatory variables. Unlike the FEM, the REM posits that the individual-specific constant terms are randomly drawn from a larger population and treated as random variables. The Hausman test is a statistical method used to determine the appropriateness of using either the fixed effects model or the random effects model. The test compares the coefficient estimates from both models to detect any systematic differences. If the estimates are similar, the REM is appropriate; otherwise, the FEM should be used. This indicates that there are substantial systematic differences between the models. Therefore, to mitigate endogeneity, this study adopts the fixed effects model for its main effects. The specific model is as follows:

$$\mathrm{NHREC}_{i,t} = \alpha_0 + \alpha_1\mathrm{RDI}_{i,t} + \alpha_2\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{1}$$

$$\mathrm{NHREC}_{i,t} = \gamma_0 + \gamma_1\mathrm{UR}_{i,t} + \gamma_2\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{2}$$

$$\mathrm{NHREC}_{i,t} = \lambda_0 + \lambda_1\mathrm{HC}_{i,t} + \lambda_2\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{3}$$

In these equations, the dependent variable $\mathrm{NHREC}_{i,t}$ represents the consumption of non-hydro renewable energy in region i and time t. The explanatory variables are research and development intensity ($\mathrm{RDI}_{i,t}$), urbanization ($\mathrm{UR}_{i,t}$), and human capital ($\mathrm{HC}_{i,t}$) in region i and time t. The control variables ($\mathrm{Con}_{i,t}$) include informationization ($\mathrm{IN}_{i,t}$), economic development ($\mathrm{ED}_{i,t}$), labor ($\mathrm{LA}_{i,t}$), fiscal support intensity ($\mathrm{FSI}_{i,t}$), transportation infrastructure ($\mathrm{TI}_{i,t}$), and openness ($\mathrm{OP}_{i,t}$) in region i and time t. The terms ν_i, υ_t, and $\xi_{i,t}$ represent individual-fixed effects, time-fixed effects, and random disturbances, respectively.

The dependent variable in Equations (1)–(3), NHREC, denotes the consumption of non-hydro renewable energy power. The explanatory variables are RDI, UR, and HC. Control variables (Con) encompass the IN, ED, LA, FSI, TI, and OP. The subscripts i and t represent provincial regions and years, respectively, while ν_i, υ_t, and $\xi_{i,t}$ denote individual-fixed effects, time-fixed effects, and random disturbance terms, respectively.

To test the significance of the explanatory variables on the dependent variable, the study proposes the following hypotheses:

H_1**:** *Research and development intensity (RDI) significantly increases the consumption of non-hydro renewable energy power (NHREC).*

The impact of RDI on NHREC can be explained through the lens of innovation diffusion theory, which emphasizes the dissemination and adoption of new technologies within socio-economic systems. The enhancement of RDI typically accompanies technological advancement and innovation, thereby improving the efficiency and reducing the costs of NHRE technologies, leading to increased utilization rates. Higher RDI also fosters the development of related industries, such as advanced energy storage and smart grid technologies, which directly support the NHREC. Additionally, provincial policies in China often include financial subsidies, tax incentives, and preferential loans to stimulate RDI in the renewable energy sector, further promoting NHREC.

H_2**:** *Urbanization (UR) significantly increases the consumption of non-hydro renewable energy power (NHREC).*

The influence of UR on NHREC is evident through increased energy demand driven by higher urban population density and economic activities. Urbanization theories suggest that economic growth and improved living standards, associated with urbanization, enhance the demand for renewable energy. The development of urban infrastructure, including renewable energy projects like wind and solar power plants, further supports NHREC. Additionally, policies and incentives aimed at promoting green energy in urbanized areas contribute to this effect. The concentration of technology and talent in urban areas also fosters innovation and the implementation of renewable energy technologies.

H_3**:** *Human capital (HC) significantly increases the consumption of non-hydro renewable energy power (NHREC).*

The role of HC in NHREC is grounded in human capital theory, which posits that higher levels of education and skills among the workforce drive technological innovation and productivity growth. Skilled human resources provide technical support and management capabilities essential for the implementation and operation of renewable energy projects, thereby enhancing energy efficiency. High-human-capital regions are better equipped to optimize energy structures, implement policies, and manage complex energy projects, thus increasing NHREC.

Post fixed effects model testing, the study explores the mechanisms by which IS and TA moderate the impacts of RDI, UR, and HC on NHREC using the moderation effect model:

$$\mathrm{NHREC}_{i,t} = \varphi_0 + \varphi_1\mathrm{RDI}_{i,t} + \varphi_2\mathrm{IS}_{i,t} + \varphi_3\mathrm{IA}_1 + \varphi_4\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{4}$$

$$\mathrm{NHREC}_{i,t} = \eta_0 + \eta_1\mathrm{RDI}_{i,t} + \eta_2\mathrm{TA}_{i,t} + \eta_3\mathrm{IA}_2 + \eta_4\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{5}$$

$$\mathrm{NHREC}_{i,t} = \vartheta_0 + \vartheta_1\mathrm{UR}_{i,t} + \vartheta_2\mathrm{IS}_{i,t} + \vartheta_3\mathrm{IA}_3 + \vartheta_4\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{6}$$

$$\mathrm{NHREC}_{i,t} = \eta_0 + \rho_1\mathrm{UR}_{i,t} + \rho_2\mathrm{TA}_{i,t} + \rho_3\mathrm{IA}_4 + \rho_4\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{7}$$

$$\mathrm{NHREC}_{i,t} = \sigma_0 + \sigma_1\mathrm{HC}_{i,t} + \sigma_2\mathrm{IS}_{i,t} + \sigma_3\mathrm{IA}_5 + \sigma_4\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{8}$$

$$\mathrm{NHREC}_{i,t} = \tau_0 + \tau_1\mathrm{HC}_{i,t} + \tau_2\mathrm{TA}_{i,t} + \tau_3\mathrm{IA}_6 + \tau_4\mathrm{Con}_{i,t} + \nu_i + \upsilon_t + \xi_{i,t} \tag{9}$$

$\mathrm{IS}_{i,t}$ and $\mathrm{TA}_{i,t}$ represent the moderating variables, industrial structure and tax, respectively. To minimize multicollinearity and simplify coefficient interpretation, core explanatory variables and moderating variables are centered. The interaction terms IA_1–IA_6 represent the centered interaction terms, and control variables have the same meaning as in Equation (1).

***H*$_4$:** *There is a moderating role of industrial structure (IS) on R&D intensity (RDI) and non-hydro renewable energy consumption (NHREC).*

IS can modulate the impact of RDI on the NHREC. When a region's industrial structure predominantly comprises high-tech and service industries, resource allocation toward innovation and technological advancements is more efficient, thereby promoting the development and application of renewable energy technologies. High-tech industries can effectively translate RDI into tangible technological outcomes, enhancing NHREC. Conversely, in regions dominated by traditional manufacturing and resource-intensive industries, RDI may be directed toward improving conventional production processes rather than renewable energy technologies, thus impeding the positive effects of RDI on NHREC. In areas with optimized industrial structures, government and corporate policies and incentives are more likely to support renewable energy R&D, amplifying RDI's positive impact on NHREC through effective policy and resource allocation.

***H*$_5$:** *There is a moderating role of industrial structure (IS) on urbanization (UR) and non-hydro renewable energy consumption (NHREC).*

IS also moderates the effect of UR on NHREC. In regions where IS leans toward high-tech industries and services, the urbanization process is accompanied by infrastructure upgrades and the promotion of green technologies, enhancing the efficiency of renewable energy utilization. For instance, urban smart energy management systems and smart grid construction can optimize energy use and improve renewable energy consumption capacity. However, in regions where resource-intensive and high-energy-consumption industries predominate, rapid urbanization may lead to the expansion of these industries, suppressing the use of renewable energy. In optimized industrial structures, government and corporate resources and policies are more likely to support green urbanization processes, fostering the development and utilization of renewable energy projects and thereby enhancing the positive modulation of urbanization on NHREC.

***H*$_6$:** *There is a moderating role of industrial structure (IS) on human capital (HC) and non-hydro renewable energy consumption (NHREC).*

IS further modulates the impact of HC on NHREC. In regions with high HC and a predominant focus on high-tech industries, human capital can fully utilize its innovation and technological application capabilities, thereby promoting the R&D and application of non-hydro renewable energy technologies. Effective deployment of high-level human resources in high-tech industries significantly boosts NHREC. However, in areas where human resources are abundant, but the industrial structure is skewed toward traditional manufacturing and resource-intensive industries, even high levels of human capital may primarily serve traditional industry development rather than renewable energy sectors. This scenario results in IS negatively modulating the positive effects of high HC on NHREC. Asymmetric policies and incentives in regions with traditional and low-tech industries may also hinder the innovative potential of human resources in the renewable energy field, thus determining whether IS positively or negatively affects the modulation of human capital on NHREC.

***H_7*:** *There is a moderating role of tax (TA) on R&D intensity (RDI) and non-hydro renewable energy consumption (NHREC).*

TA moderates the relationship between RDI and NHREC. According to tax incentive theory, a moderate tax can encourage firms to increase their R&D investments through tax incentives and financial subsidies. A lower tax reduces the operational costs for companies, allowing them to allocate more resources toward R&D activities, thereby promoting innovation and the application of renewable energy technologies, which increases NHREC. Conversely, a high tax may inhibit R&D activities by increasing operational costs and limiting funds available for R&D, thereby weakening technological innovation and reducing NHREC. Policy compatibility also plays a significant role; tax policies that align with R&D incentives, such as offering tax credits and deductions for R&D expenses, can further enhance the positive impact of RDI on NHREC.

***H_8*:** *There is a moderating role of tax (TA) on urbanization (UR) and non-hydro renewable energy consumption (NHREC).*

The TA also moderates the impact of UR on NHREC. Urban economic development theory suggests that a reasonable tax supports urban infrastructure development and environmental protection policies, which in turn promote the development and utilization of renewable energy projects. A lower tax reduces the financial burdens on urban development and corporate investments, increasing investments in renewable energy projects and improving NHREC. Conversely, a high tax may suppress urban development and infrastructure investments, slowing down urbanization and limiting the promotion and application of renewable energy projects. High taxes increase the costs of urban construction and corporate operations, weakening the positive impact of urbanization on NHREC. Government support and incentives through tax reductions and financial subsidies for green urban infrastructure and renewable energy projects can further strengthen the positive impact of urbanization on NHREC.

***H_9*:** *There is a moderating role of tax (TA) on human capital (HC) and non-hydro renewable energy consumption (NHREC).*

The TA moderates the relationship between HC and NHREC. Human capital accumulation theory posits that a moderate tax can increase investments in education and training by reducing the tax on businesses and individuals, thus promoting human capital accumulation and enhancement. A lower tax provides more resources for businesses and individuals to improve skills and knowledge, thereby driving the R&D and the application of non-hydro renewable energy technologies and increasing NHREC. Conversely, a high tax may negatively affect human capital accumulation by increasing financial pressure on businesses and individuals, limiting investments in education and training, and weakening the improvement of human capital levels, thereby reducing NHREC. The combination of tax policies with education and training incentives also plays an important role in the moderating effect. Tax policies that provide deductions for education and training expenses can further enhance the positive impact of human capital levels on NHREC.

4. Results and Analysis

4.1. Descriptive Statistical Analysis of Provincial Data in China

The descriptive statistics presented in Table 1 provide insightful information about the variations and distributions of key variables related to non-hydro renewable energy consumption across Chinese provinces. The mean NHREC of 5.031, with a standard deviation (SD) of 1.055, indicates substantial variability in renewable energy consumption across provinces. Its coefficient of variance (CV) is 20.970%. This suggests differences in the adoption and utilization of renewable energy technologies, potentially influenced by regional policies, resource availability, and economic development levels.

Table 1. Descriptive statistics of variables.

Variable	Size	Mean	SD	CV	Min	Max
NHREC	248	5.031	1.055	20.970%	1.386	7.116
RDI		0.021	0.015	71.429%	0	0.070
UR		0.617	0.117	18.963%	0.290	0.890
HC		0.022	0.006	27.273%	0.010	0.044
IS		1.487	0.76	51.110%	0.760	5.280
TA		0.08	0.028	35.000%	0.036	0.188
IN		0.075	0.060	80.000%	0.015	0.290
ED		11.008	0.413	3.752%	10.164	12.155
LA		7.519	0.862	11.464%	5.198	8.864
FSI		0.291	0.203	69.759%	0.105	1.354
TI		11.568	1.054	9.111%	7.586	12.939
OP		0.239	0.235	98.326%	0.008	1.038

The average RDI is 0.021, with a standard deviation of 0.015, reflecting considerable variation in R&D efforts across provinces. Higher R&D intensity typically correlates with increased innovation and technological advancements, which are crucial for improving renewable energy efficiency and reducing costs. The mean urbanization of 0.617, with a relatively low standard deviation of 0.117, indicates a fairly uniform distribution of urbanization across provinces. Urbanization is linked to higher energy demand and infrastructure development, which can drive the adoption of renewable energy sources.

The mean HC of 0.022 and a standard deviation of 0.006 highlight significant differences in human capital. Higher human capital, characterized by a more educated and skilled workforce, is essential for innovation, management, and the efficient implementation of renewable energy projects. The mean IS of 1.487, with a standard deviation of 0.76, suggests diverse industrial compositions among provinces. Regions with more advanced industrial structures are likely better positioned to support renewable energy technologies through improved infrastructure and greater resource allocation toward innovation.

The average TA is 0.08, with a standard deviation of 0.028, indicating differences in the fiscal environments of the provinces. A lower tax can encourage investments in renewable energy by reducing the financial constraints on businesses and individuals. The mean IN of 0.075, with a standard deviation of 0.06, reflects variability in the digitalization and informatization of provinces. Higher informatization can enhance energy management and efficiency, promoting greater adoption of renewable energy technologies.

The average ED of 11.008, with a standard deviation of 0.413, shows variation in economic prosperity among provinces. Wealthier regions are likely to have more resources and incentives to invest in renewable energy infrastructure and technologies. The mean LA of 7.519, with a standard deviation of 0.862, indicates differences in the availability of labor across provinces. A larger labor force can support the development and maintenance of renewable energy projects. The mean FSI of 0.291, with a standard deviation of 0.203, highlights disparities in government support for renewable energy. Greater fiscal support can incentivize renewable energy investments and development.

The mean TI of 11.568, with a standard deviation of 1.054, reflects variations in infrastructure quality. Robust transportation infrastructure is crucial for the distribution and accessibility of renewable energy. The average degree of OP of 0.239, with a standard deviation of 0.235, suggests significant differences in the openness to trade and international cooperation. Higher openness can facilitate the exchange of technologies and investments in renewable energy.

The variability in these key variables across Chinese provinces underscores the complex interplay of factors influencing the consumption of non-hydro renewable energy power. These differences highlight the need for tailored regional policies that consider specific local conditions and strengths to effectively promote renewable energy adoption and sustainable development.

4.2. Baseline Regression Analysis

The baseline regression results in Table 2 and Figure 4 provide critical insights into the relationship between RDI and the consumption of NHREC across Chinese provinces. Each model variant demonstrates the robustness and consistency of this relationship under different controls and fixed effects.

Table 2. Baseline regression on the relationship between RDI and NHREC.

	(1)	**(2)**	**(3)**	**(4)**
Variable	**NHREC**			
RDI	53.17 *** (8.889)	15.90 *** (6.039)	21.53 *** (6.584)	22.84 *** (6.481)
Control	No	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
Time FE	No	No	No	Yes
R^2	0.281	0.866	0.876	0.894
White test	-	-	-	$\chi^2 = 248$ $p > 0.05$

Note: Standard errors are in parentheses. *** $p < 0.01$.

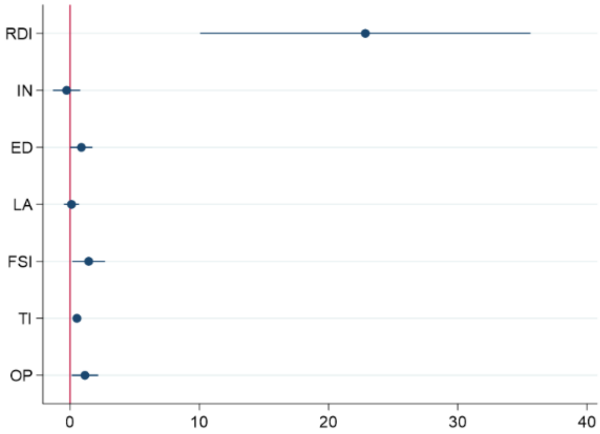


Figure 4. Coefficients interval on the relationship between RDI and NHREC. Note: The *x*-axis in Figures 4–6 now includes the unit of measurement for the coefficients interval, labeled as "Coefficient Interval (unitless)".

The regression analysis demonstrates that RDI significantly influences the NHREC across Chinese provinces. The results show robustness and consistency under various controls and fixed effects. The coefficient for RDI in Model (1) is 53.17 ($p < 0.01$), with an R^2 of 0.281, indicating that, without controls, RDI substantially boosts NHREC and explains a significant portion of its variance among provinces. When control variables are introduced in Model (2), the RDI coefficient decreases to 15.90 ($p < 0.01$), and the R^2

increases dramatically to 0.866. This highlights the critical role of other factors such as economic development, infrastructure, and regional policies in influencing NHREC.

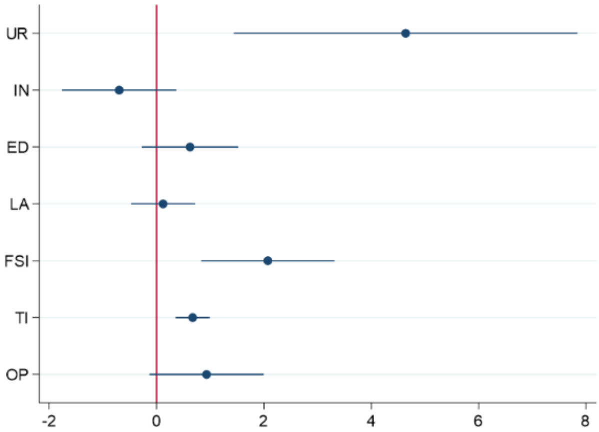


Figure 5. Coefficients interval on the relationship between UR and NHREC.

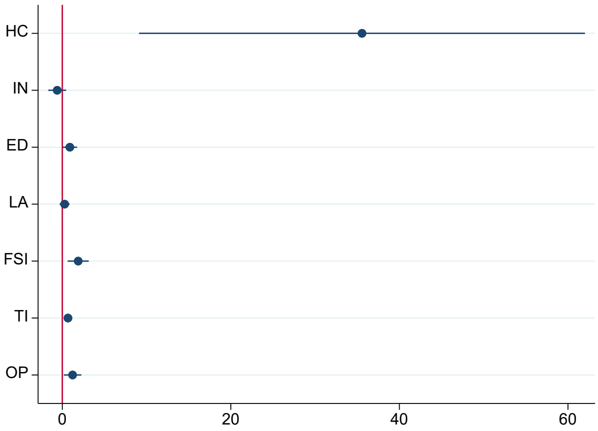


Figure 6. Coefficients interval on the relationship between HC and NHREC.

The White test is a widely used method in econometrics for detecting heteroskedasticity in regression models. As shown in Figure 4 and Table 2, the test results indicate that after controlling for individual-fixed effects and time-fixed effects, the White test was employed to detect heteroskedasticity in the model. The χ^2 statistic for the White test is 248 ($p > 0.05$), suggesting that the model specification is robust. This means we accept the null hypothesis that there is no heteroskedasticity in the model, which further enhances the reliability of the baseline regression results.

Incorporating individual-fixed effects in Model (3), the RDI coefficient increases to 21.53 ($p < 0.01$), with an R^2 of 0.876. This suggests that individual province characteristics significantly influence the relationship between RDI and NHREC, accounting for unobserved heterogeneity across provinces. Including both individual- and time-fixed effects in Model (4), the RDI coefficient is 22.84 ($p < 0.01$), with an R^2 of 0.894. This model controls for time-invariant characteristics and temporal effects, providing the most comprehensive analysis.

The findings consistently show that increased RDI leads to higher NHREC, underscoring the crucial role of research and development in promoting renewable energy consumption. The positive and significant impact of RDI across all models indicates that investments in R&D enhance the efficiency and adoption of renewable energy technologies, driving substantial increases in non-hydro renewable energy consumption. The decreasing but still significant coefficients of RDI in the presence of controls and fixed effects suggest that while RDI is a key driver, other factors such as economic development, infrastructure, and regional policies also play significant roles. This highlights the multifaceted nature of renewable energy adoption, where technological innovation driven by R&D must be supported by favorable economic and infrastructural conditions to maximize its impact.

The baseline regression results in Table 3 and Figure 5 offer critical insights into the relationship between UR and NHREC across Chinese provinces. The robustness and consistency of this relationship are demonstrated across model variations (5)–(8), which incorporate different controls and fixed effects.

Table 3. Baseline regression on the relationship between UR and NHREC.

	(5)	**(6)**	**(7)**	**(8)**
Variable		**NHREC**		
UR	16.23 *** (0.739)	4.609 *** (1.377)	6.813 *** (1.550)	4.641 *** (1.623)
Control	No	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
Time FE	No	No	No	Yes
R^2	0.804	0.865	0.881	0.892
White test	-	-	-	$\chi^2 = 248$ $p > 0.05$

Note: Standard errors are in parentheses. *** $p < 0.01$.

The regression analysis reveals the significant impact of UR on the consumption of non-hydro renewable energy power NHREC across Chinese provinces. Models (5)–(8) consistently demonstrate the robustness and reliability of this relationship under various controls and fixed effects.

The coefficient for UR in Model (5) is 16.23 ($p < 0.01$), with an R^2 of 0.804, indicating that, without controls, an increase in UR substantially boosts NHREC and explains a significant portion of its variance among provinces. Introducing control variables in Model (6) decreases the UR coefficient to 4.609 ($p < 0.01$) while the R^2 value increases to 0.865, highlighting the significant role of other factors, such as economic development and infrastructure, in influencing NHREC.

Based on the information provided in Figure 5 and Table 3, after controlling for individual-fixed effects and time-fixed effects, the χ^2 statistic for the White test is 248 ($p > 0.05$), indicating that the model specification is robust. This means we accept the null hypothesis that there is no heteroskedasticity in the model. The test results further enhance the reliability of the baseline regression results, indicating that the variables used can adequately explain the variations in NHREC without being affected by heteroskedasticity.

Incorporating individual-fixed effects in Model (7), the UR coefficient increases slightly to 6.813 ($p < 0.01$) with an R^2 of 0.881, suggesting that provincial characteristics significantly influence the UR-NHREC relationship, accounting for unobserved heterogeneity across provinces. Including both individual- and time-fixed effects in Model (8), the UR coefficient is 4.641 ($p < 0.01$) with an R^2 of 0.892, providing the most rigorous analysis by controlling for time-invariant characteristics and temporal effects.

The consistent positive and significant impact of UR on NHREC across all models underscores the critical role of urbanization in promoting renewable energy consumption. Urbanization drives the demand for renewable energy through increased economic activities, higher population density, and improved infrastructure. This relationship indicates that as urban areas expand, the adoption and consumption of renewable energy technologies increase.

The varying coefficients of UR, while still significant in the presence of controls and fixed effects, suggest that factors such as economic development, infrastructure quality, and regional policies also play crucial roles. These findings highlight the multifaceted nature of renewable energy adoption, where urbanization must be supported by favorable economic and infrastructural conditions to maximize its impact. The results emphasize the need for a comprehensive understanding of how urbanization interacts with other determinants to drive renewable energy consumption effectively.

The baseline regression results in Table 4 provide significant insights into the relationship between HC and NHREC across Chinese provinces. Each model variation (9)–(12) demonstrates the robustness and consistency of this relationship under different controls and fixed effects.

Table 4. Baseline regression on the relationship between HC and NHREC.

	(9)	**(10)**	**(11)**	**(12)**
Variable	**NHREC**			
HC	167.7 *** (8.901)	47.89 *** (10.26)	33.06 *** (11.57)	35.56 *** (13.42)
Control	No	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
Time FE	No	No	No	Yes
R^2	0.662	0.869	0.875	0.891
White test	-	-	-	$\chi^2 = 248$ $p > 0.05$

Note: Standard errors are in parentheses. *** $p < 0.01$.

The regression analysis reveals the significant impact of HC on the NHREC across Chinese provinces. Models (9)–(12) consistently demonstrate the robustness and reliability of this relationship under various controls and fixed effects.

According to the data presented in Figure 6 and Table 4, after controlling for individual-fixed effects and time-fixed effects, the χ^2 statistic for the White test is 248 ($p > 0.05$), indicating that the model specification is robust. This means we accept the null hypothesis that there is no heteroskedasticity in the model. The test results further validate the reliability of the baseline regression results, indicating that the variables used can adequately explain the variations in non-hydro renewable energy consumption without being affected by heteroskedasticity.

The coefficient for HC in Model (9) is 167.7 ($p < 0.01$), with an R^2 of 0.662, indicating that, without controls, an increase in HC significantly boosts NHREC and explains a substantial portion of its variance among provinces. Introducing control variables in Model (10) decreases the HC coefficient to 47.89 ($p < 0.01$), while the R^2 value increases to 0.869. This highlights the significant role of other factors, such as economic development and infrastructure, in influencing NHREC.

Incorporating individual-fixed effects in Model (11), the HC coefficient decreases further to 33.06 ($p < 0.01$), with an R^2 of 0.875, suggesting that provincial characteristics significantly influence the HC-NHREC relationship, accounting for unobserved heterogeneity across provinces. Including both individual- and time-fixed effects in Model (12), the HC coefficient is 35.56 ($p < 0.01$), with an R^2 of 0.891, providing the most rigorous analysis by controlling for time-invariant characteristics and temporal effects.

The consistent positive and significant impact of HC on NHREC across all models underscores the critical role of human capital in promoting renewable energy consumption. Human capital drives the adoption and efficiency of renewable energy technologies through enhanced skills, education, and innovation. As the level of human capital increases, so does the capacity to implement and optimize renewable energy solutions, leading to higher consumption of non-hydro renewable energy.

The varying coefficients of HC, while still significant in the presence of controls and fixed effects, suggest that factors such as economic development, infrastructure quality, and regional policies also play crucial roles. These findings highlight the multifaceted nature of renewable energy adoption, where human capital development must be supported by favorable economic and infrastructural conditions to maximize its impact. The results emphasize the need for a comprehensive understanding of how human capital interacts with other determinants to drive renewable energy consumption effectively.

4.3. Robustness Checks

The robustness tests presented in Table 5 provide substantial insights into the relationship between various explanatory variables—RDI, UR, and HC—and the NHREC across Chinese provinces. This analysis evaluates these relationships under different weighting schemes and model specifications, thereby demonstrating the consistency and reliability of the findings.

Table 5. The results of robustness tests.

	(13)	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**
Variable	**NHREC$_W$**	**NHREC$_P$**	**NHREC$_W$**	**NHREC$_P$**	**NHREC$_W$**	**NHREC$_P$**
RDI	-	26.59 *** (7.291)	-	-	-	-
RDI$_W$	23.29 *** (6.528)	-	-	-	-	-
UR	-	-	-	5.250 *** (1.670)	-	-
RU$_W$	-	-	5.184 *** (1.553)	-	-	-
HC	-	-	-	-	-	30.28 ** (14.04)
HC$_W$	-	-	-	-	41.13 *** (13.29)	-
Control	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.891	0.903	0.890	0.901	0.890	0.898

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$.

The study further verifies the impacts of RDI, UR, and HC on NHREC through two robustness checks: winsorizing and the exclusion of specific years. In models (13), (15), and (17), the coefficients of the core variables remain significant after applying a [1%, 99%] winsorizing, indicating the robustness and reliability of their effects on NHREC$_W$. Specifically, the coefficient for RDI$_W$ is 23.29 ($p < 0.01$) with a standard error of 6.528, the coefficient for UR$_W$ is 5.184 ($p < 0.01$) with a standard error of 1.553, and the coefficient for HC$_W$ is 41.13 ($p < 0.01$) with a standard error of 13.29. The R^2 values for these models are 0.891, 0.890, and 0.890, respectively, indicating high explanatory power.

In Models (14), (16), and (18), data from the year 2020 are excluded due to the COVID-19 pandemic. The coefficients for the core variables remain significant, reaffirming their impact on NHREC$_P$. The coefficient for RDI is 26.59 ($p < 0.01$) with a standard error of 7.291, the coefficient for UR is 5.250 ($p < 0.01$) with a standard error of 1.670, and the coefficient for HC is 30.28 ($p < 0.05$) with a standard error of 14.04. The R^2 values for these models are 0.903, 0.901, and 0.898, respectively, indicating robust explanatory power.

The robustness tests confirm the positive and significant impacts of RDI, UR, and HC on NHREC across different model specifications and robustness checks. These findings underscore the critical importance of RDI, UR, and HC in promoting renewable energy consumption. Even with winsorizing and the exclusion of 2020 data, the core explanatory variables consistently show significant effects, further validating the reliability and consistency of the study's results. Policymakers should consider these factors when designing strategies to increase the adoption and utilization of non-hydro renewable energy, ensuring that efforts are directed toward enhancing R&D capabilities, supporting urban development, and investing in human capital.

4.4. Endogeneity Tests

The endogeneity tests presented in Table 6 validate the use of lagged variables as instruments for RDI, UR, and HC in assessing their impact on the NHREC across Chinese provinces.

Table 6. The results of endogeneity test.

	(19)	**(20)**	**(21)**
Variable		**NHREC**	
RDI	26.17 *** (9.213)	-	-
UR	-	16.50 *** (4.278)	-
HC	-	-	236.6 *** (65.75)
Control	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Anderson canon. corr. LM statistic	127.423	45.104	21.751
Cragg–Donald Wald F statistic	246.093	45.128	19.516

Note: Standard errors are in parentheses. *** $p < 0.01$.

The coefficient for RDI in Model (19) is 26.17 ($p < 0.01$), with an Anderson canonical correlation LM statistic of 127.423 and a Cragg–Donald Wald F statistic of 246.093. These statistics indicate that lagged RDI is a robust instrument, addressing potential endogeneity concerns. The significant positive impact of RDI on NHREC underscores the crucial role of research and development in driving renewable energy adoption.

In Model (20), the coefficient for UR is 16.50 ($p < 0.01$), with an Anderson canonical correlation LM statistic of 45.104 and a Cragg–Donald Wald F statistic of 45.128. These results confirm that lagged social consumption level is a valid instrument for UR, reinforcing the importance of urbanization in promoting renewable energy consumption through enhanced economic activities and infrastructure development.

Model (21) reports a coefficient for human capital (HC) at 236.6 with statistical significance ($p < 0.01$). The Anderson canonical correlation LM statistic is 21.751, and the Cragg–Donald Wald F statistic stands at 19.516, justifying the use of industrialization level as an instrument for HC. This finding underscores the pivotal role of human capital in advancing renewable energy technologies through enhanced education and skills.

The analysis reveals that research and development intensity (RDI), urbanization (UR), and HC significantly impact non-hydro renewable energy consumption (NHREC). The robust instruments used in these models validate the reliability of the coefficients, highlighting the critical importance of addressing potential endogeneity. The study demonstrates that RDI, UR, and HC are essential for increasing renewable energy consumption.

The positive impacts of RDI, UR, and HC on NHREC illustrate the complexity of renewable energy adoption. R&D efforts lead to technological innovations that reduce costs and improve the efficiency of renewable energy technologies. Urbanization fosters infrastructure development and economic growth, which are crucial for the deployment of renewable energy. Additionally, a well-educated and skilled workforce enhances the capacity to implement and optimize renewable energy solutions.

The economic implications are significant. R&D stimulates innovation and creates an environment conducive to the diffusion of advanced renewable energy technologies, thereby reducing costs and enhancing efficiency. This, in turn, leads to broader adoption of renewable energy, contributing to energy security and environmental sustainability.

Urbanization increases energy demand but also provides the infrastructure necessary for integrating renewable energy into the energy mix. The development of smart grids, green buildings, and urban planning that incorporates renewable energy sources is facilitated by urbanization, which boosts renewable energy consumption.

Human capital is fundamental to technological adoption and efficiency. A skilled and educated workforce is essential for the research, development, and implementation of renewable energy technologies. Investing in education and training programs ensures a steady supply of qualified individuals capable of driving the renewable energy sector.

These findings highlight the need for policies that support R&D, promote sustainable urbanization, and invest in human capital. Such policies can create a synergistic effect, enhancing the adoption and utilization of renewable energy and leading to economic growth, job creation, and environmental benefits. Managing the interplay between these factors is crucial for achieving a balanced and sustainable energy future.

4.5. Heterogeneity Analysis

Given the uneven development across regions in China, this study examines the regional disparities in the effects of RDI, UR, and HC on NHREC. The sample is divided into four regions—eastern, central, western, and northeastern—according to the National Bureau of Statistics' economic zones to determine whether these factors exhibit region-specific impacts on NHREC. Zhao et al. [25] propose an optimized allocation plan for renewable energy quota standards across 30 Chinese provinces. This plan, developed using a bi-level programming model combined with the entropy weight method, aims to foster the development of renewable energy while considering provincial heterogeneity and stakeholder behavior.

This study employs the Natural Breaks Classification method in ArcGIS 10.8 to analyze the NHREC across 31 provincial-level administrative regions in China, excluding Taiwan, Hong Kong, and Macau. The Natural Breaks Classification, also known as the Jenks optimization method, identifies optimal classification points by maximizing within-class homogeneity and minimizing between-class heterogeneity, utilizing an iterative algorithm to determine natural breakpoints in the data.

The application of this method in data visualization offers several advantages. It highlights the natural distribution of data by automatically finding separation points, reducing potential misinterpretations that can arise from arbitrarily set classification points and enhancing readability by making classified charts easier to interpret, particularly in spatial data presentations.

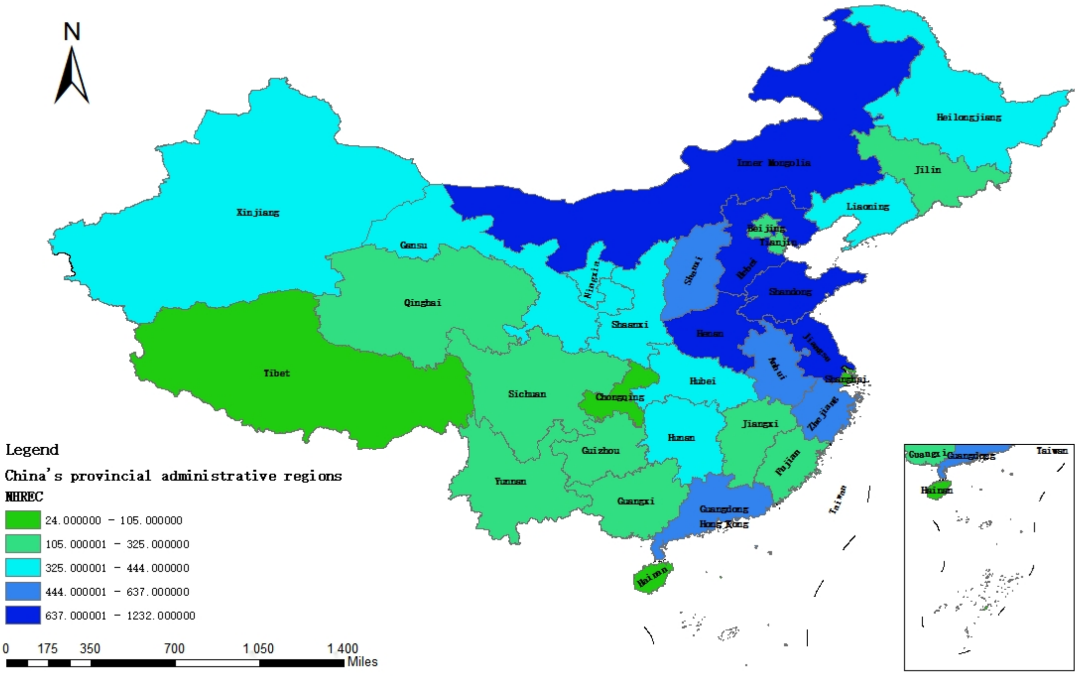
Given the uneven and insufficient development across various regions in China, the NHREC varies significantly among the provincial-level administrative regions. By employing ArcGIS 10.8 and the Natural Breaks Classification method, this study categorizes NHREC into five levels across these regions, providing a clear visualization of the differences. The results, illustrated in Figures 7–10, demonstrate substantial regional disparities in NHREC. High-consumption areas such as Inner Mongolia and Xinjiang exhibit elevated NHREC due to their abundant wind and solar resources. Medium-consumption areas like Hebei and Shanxi display moderate NHREC levels, while low-consumption areas, including economically developed but resource-scarce regions such as Beijing and Shanghai, show lower NHREC levels.

Figures 7–10 show the spatial distribution of NHREC across China's provincial administrative regions from 2015 to 2022.

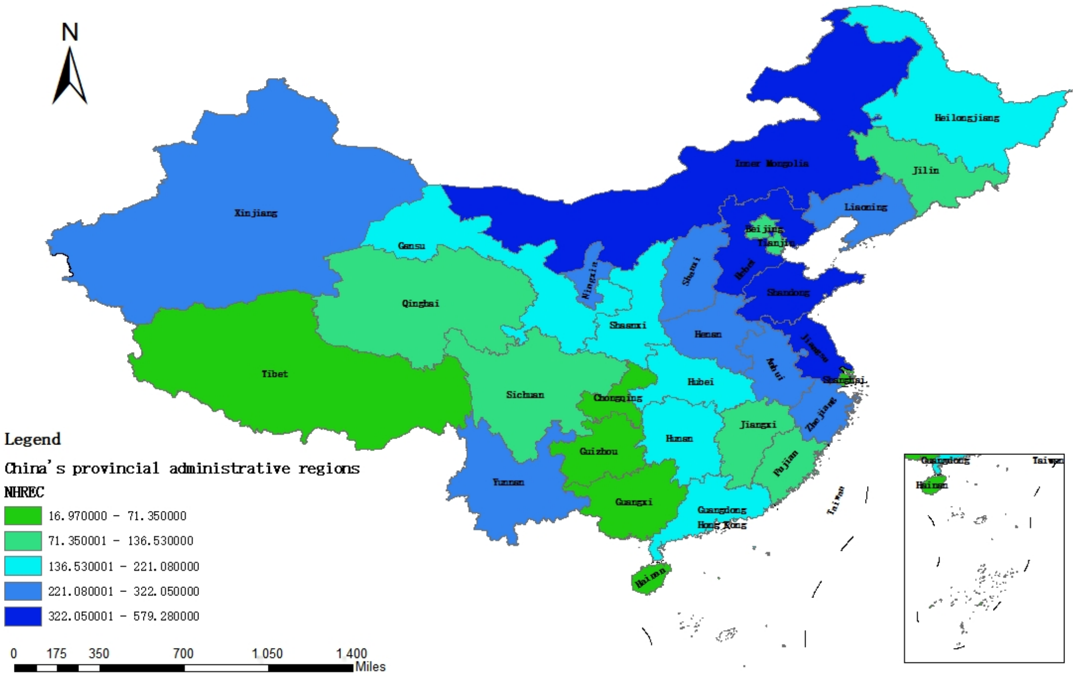
These findings suggest that the spatial distribution of NHREC is closely related to regional resource endowments, economic development levels, and the extent of policy support. The refined spatial analysis presented in this study provides robust empirical support and a theoretical basis for understanding the NHREC across China's provincial-level administrative regions.

Table 7 presents the heterogeneity test results, highlighting the impact of RDI on the NHREC across different regions in China. The regions are categorized as eastern, central, western, and northeastern, revealing significant regional disparities in the influence of RDI on NHREC.

The central region exhibits the most substantial positive impact of RDI on NHREC, with a coefficient of 91.92 ($p < 0.01$). This significant effect suggests that the central region's investment in research and development is highly effective in promoting renewable energy consumption. The strong RDI influence reflects robust policy support and technological innovation, highlighting the region's capacity to leverage R&D investments to enhance renewable energy adoption. The high R^2 value of 0.982 indicates that the model explains a significant portion of the variance in NHREC, underscoring the importance of RDI in this region.



NHREC in 2022.



NHREC in 2018.

Figure 7. *Cont.*

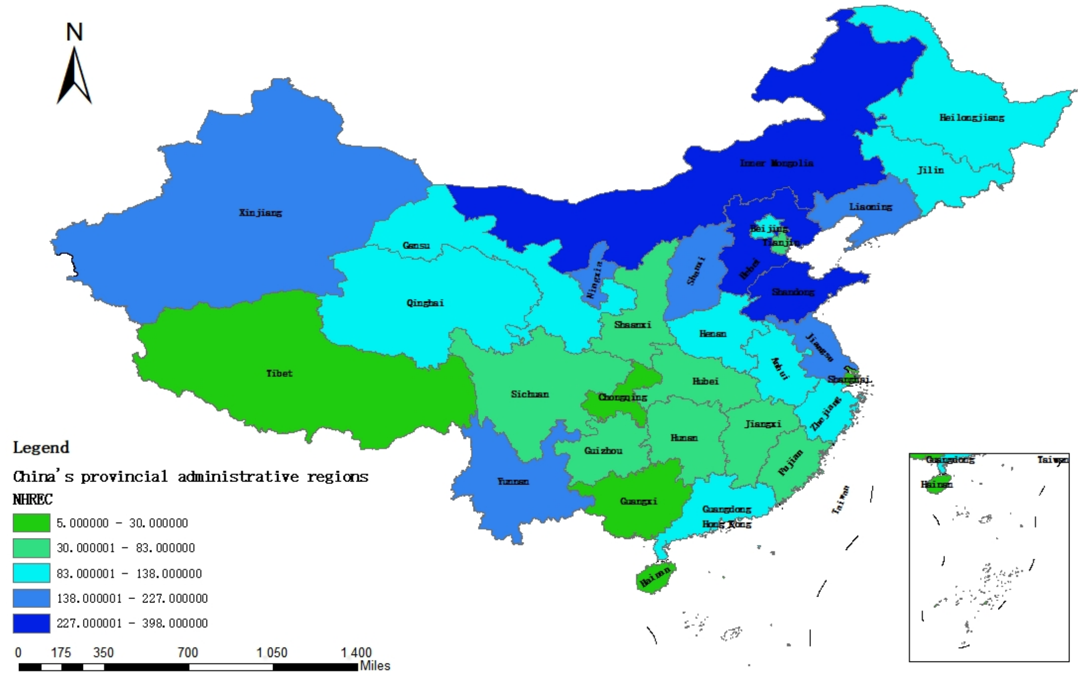
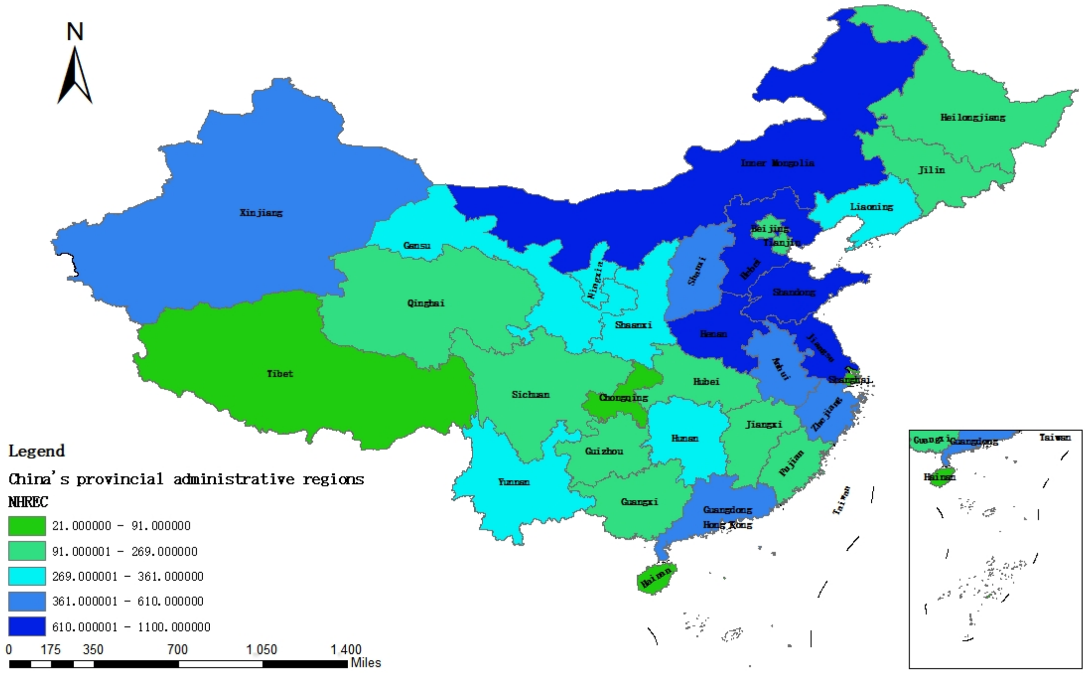


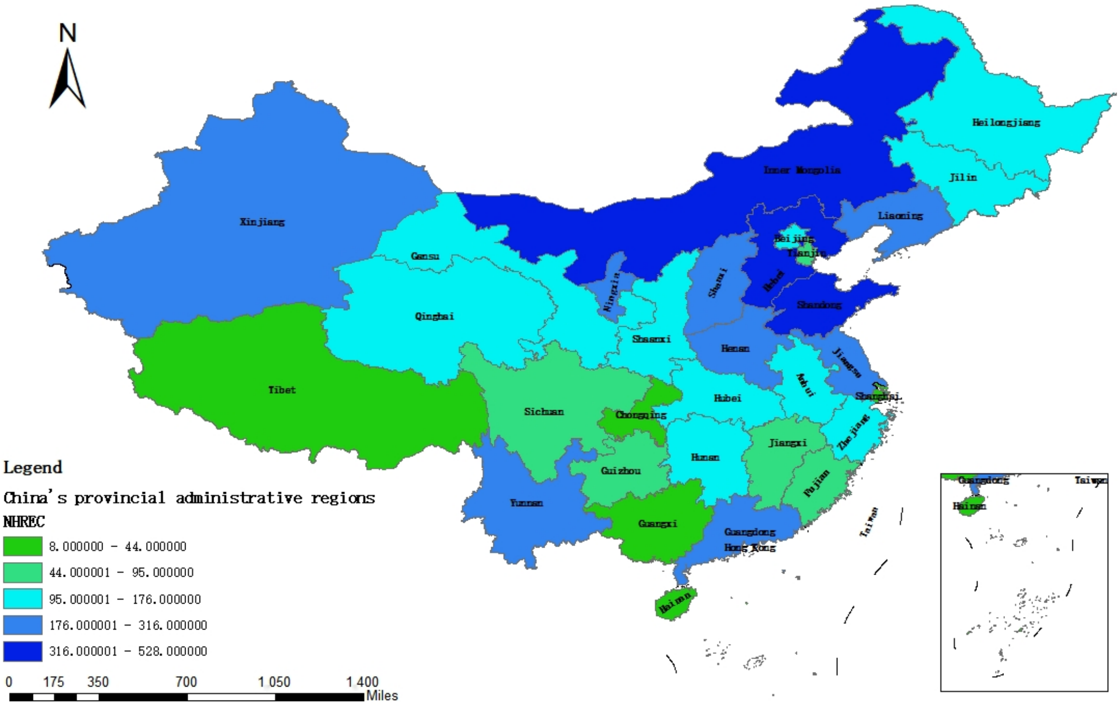
Figure 7. NHREC in 2016, 2018, and 2022.

In the western region, the RDI coefficient is 31.44 ($p < 0.05$), indicating a significant positive impact, albeit lower than in the central region. This disparity might be attributed to the Western region's relatively lower economic development, which could limit the full realization of R&D investments' potential benefits. Nevertheless, the significant effect demonstrates that increased R&D efforts can still substantially enhance renewable energy consumption in the region. The R^2 value of 0.872 reflects a good model fit, highlighting the relevance of RDI in explaining NHREC variance.

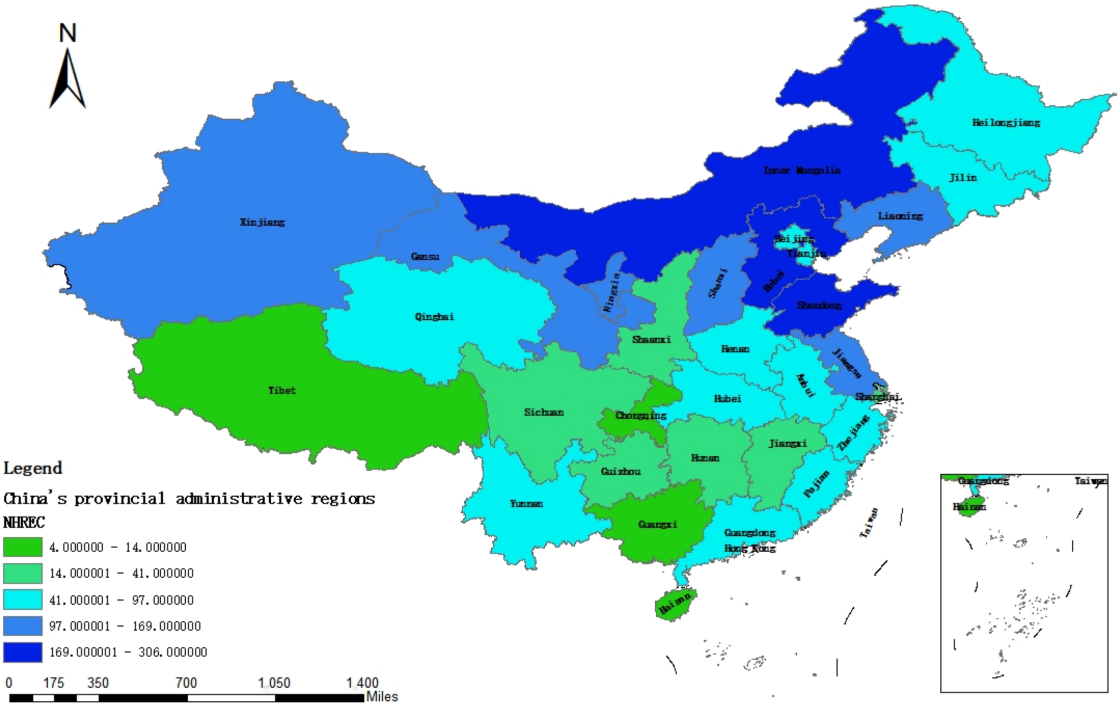


NHREC in 2021.

Figure 8. *Cont*.



NHREC in 2017.



NHREC in 2015.

Figure 8. NHREC in 2015, 2017, and 2021.

The Eastern region shows a non-significant RDI coefficient of −0.104. This lack of significance might be due to the already high levels of renewable energy consumption and well-established infrastructure in the eastern region, resulting in diminishing marginal returns from additional R&D investments. The region's energy policies might also be focused on other areas, reducing the relative impact of RDI on NHREC. The R^2 value of 0.971 indicates a strong model fit, even though RDI does not significantly influence NHREC.

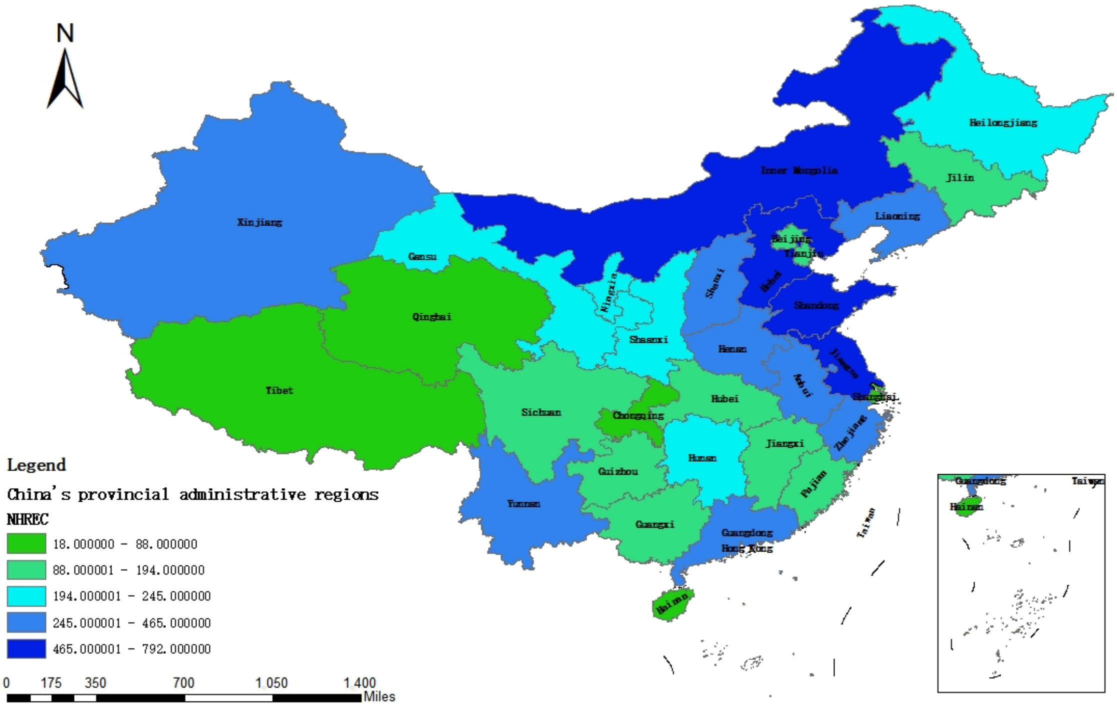


Figure 9. NHREC in 2020.

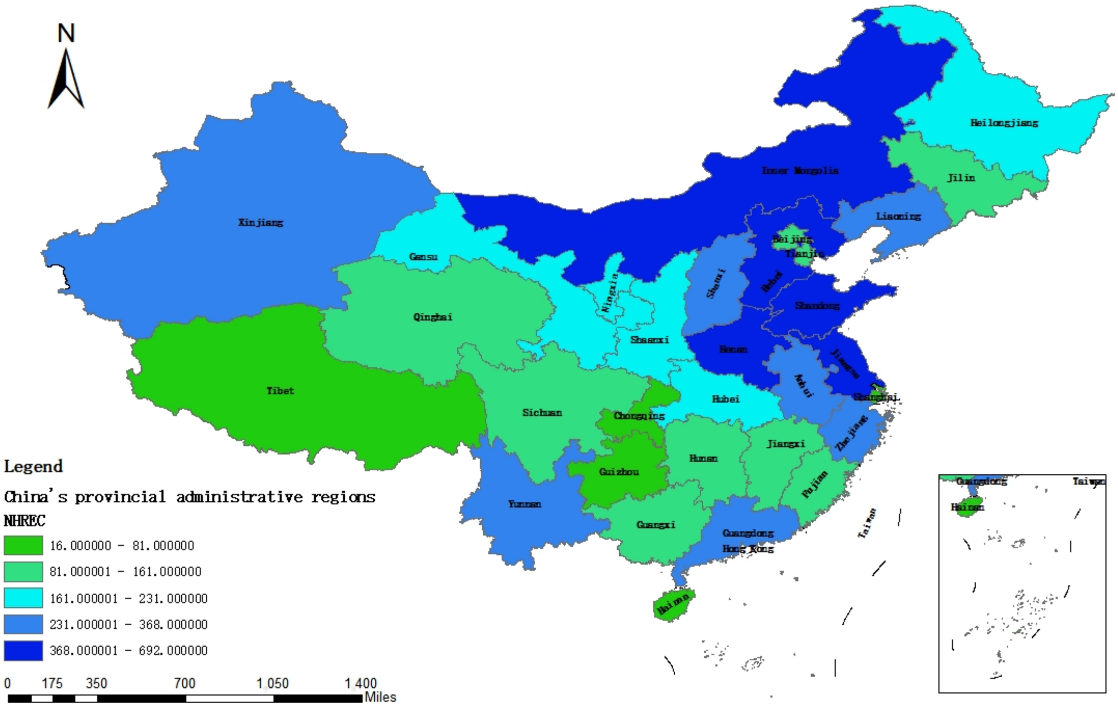


Figure 10. NHREC in 2019.

In the northeastern region, the RDI coefficient is 4.937, which is not statistically significant. The lack of significant impact might be due to weaker infrastructure and less effective policy support compared to other regions. The northeastern region faces economic challenges, and its industrial base may not be as conducive to leveraging R&D for renewable energy advancements. The high R^2 value of 0.993 suggests a strong model fit, indicating that while RDI's direct impact is limited, other factors are well accounted for in explaining NHREC variance.

The heterogeneity analysis underscores the importance of region-specific strategies in promoting renewable energy consumption through R&D investments. The significant positive impacts in the central and western regions highlight the potential of targeted R&D policies to drive renewable energy adoption in areas where economic development and policy support align effectively with technological advancements.

Table 7. Heterogeneity test on the relationship between RDI and NHREC.

Region	Eastern	Central	Western	Northeastern
Variable		**NHREC**		
RDI	−0.104 (5.457)	91.92 *** (31.27)	31.44 ** (13.72)	4.937 (20.71)
Control	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
R^2	0.971	0.982	0.872	0.993
Number of Provinces	10	6	12	3

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$.

In the central region, the strong impact of RDI reflects substantial policy support and technological innovation. This region's capacity to leverage R&D investments to enhance renewable energy adoption is significant, suggesting that continued investment in research and development is crucial for maintaining and increasing renewable energy consumption. In the western region, although the impact of RDI is lower, it remains significant, indicating that increased R&D efforts can enhance renewable energy consumption despite the region's lower economic development level. The significant effect of RDI in this region suggests that policies promoting R&D can be effective in driving renewable energy adoption, even in less economically developed areas.

The non-significant results in the eastern and northeastern regions indicate the need for tailored approaches. In the eastern region, policies might need to focus on optimizing existing infrastructure and exploring new areas of innovation beyond current R&D efforts. The high levels of renewable energy consumption and well-established infrastructure in this region suggest that additional R&D investments may have diminishing marginal returns. For the northeastern region, enhancing infrastructure, economic incentives, and policy support could make R&D investments more effective in boosting renewable energy consumption. The economic challenges and industrial decline in this region highlight the need for comprehensive strategies that address both infrastructure and policy support to maximize the impact of R&D on renewable energy adoption.

The heterogeneity test results reveal that the impact of RDI on NHREC varies significantly across different regions in China, emphasizing the need for tailored regional policies. The central and western regions benefit substantially from R&D investments, while the eastern and northeastern regions require different strategies to enhance renewable energy consumption. These findings highlight the multifaceted nature of renewable energy adoption and the critical role of region-specific economic and policy environments in leveraging R&D for sustainable energy development. Understanding these regional disparities is essential for designing effective policies that maximize the utilization of non-hydro renewable energy and contribute to sustainable development goals.

Table 8 presents the heterogeneity test results, highlighting the impact of UR on the NHREC across different regions in China. The regions are categorized as eastern, central, western, and northeastern, revealing significant regional disparities in the influence of UR on NHREC.

The analysis reveals significant regional disparities in the impact of UR on NHREC across different regions in China. In the central region, UR shows a substantial positive effect on NHREC, with a coefficient of 22.05 ($p < 0.01$). This indicates that rapid urbanization in the central region significantly enhances the adoption of renewable energy. The improvement in infrastructure and economic activities associated with urbanization likely creates a conducive environment for integrating renewable energy sources. The model's high R^2 value of 0.986 underscores the critical role of urbanization in this region's energy consumption dynamics.

Table 8. Heterogeneity test on the relationship between UR and NHREC.

Region	Eastern	Central	Western	Northeastern
Variable		**NHREC**		
UR	1.719 (1.386)	22.05 *** (5.055)	−0.0655 (5.598)	−0.840 (6.802)
Control	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
R^2	0.972	0.986	0.862	0.992
Number of Provinces	10	6	12	3

Note: Standard errors are in parentheses. *** $p < 0.01$.

In contrast, the eastern region exhibits a non-significant UR coefficient of 1.719, suggesting that further urbanization has limited marginal effects on NHREC. This may be due to the already high levels of urbanization in the region, where additional urban growth does not significantly influence renewable energy consumption. The high R^2 value of 0.972 indicates that while urbanization is accounted for in the model, its impact may have plateaued or been overshadowed by other factors.

The western region shows a non-significant UR coefficient of −0.0655, indicating that urbanization has not had a substantial positive effect on NHREC. This may be attributed to slower urbanization progress, insufficient infrastructure, and inadequate policy support in the region. The lower economic development level may also hinder the potential benefits of urbanization on renewable energy adoption. The R^2 value of 0.862 suggests that other factors may better explain NHREC variance in this region, highlighting the need for improved urbanization strategies and policy support.

Similarly, the northeastern region's non-significant UR coefficient of −0.840 reflects challenges such as economic difficulties, industrial decline, and weaker infrastructure. These factors may limit the positive impact of urbanization on renewable energy consumption. The high R^2 value of 0.992 indicates that urbanization alone does not significantly influence NHREC in this region.

The heterogeneity analysis highlights the need for region-specific strategies to promote renewable energy consumption through urbanization. The significant positive impact of UR in the central region suggests that targeted urbanization policies can effectively drive renewable energy adoption by aligning urban development with infrastructure improvements. This region's success indicates that urbanization, coupled with supportive policies, can create a favorable environment for renewable energy integration.

In contrast, the eastern, western, and northeastern regions require tailored approaches. In the eastern region, where urbanization is advanced, efforts may need to focus on optimizing existing infrastructure and exploring new technological innovations. For the western and northeastern regions, enhancing infrastructure, providing economic incentives, and strengthening policy support could make urbanization more effective in promoting renewable energy consumption. Coordinated efforts to improve urbanization processes and related infrastructure in these regions could unlock the potential benefits of increased renewable energy utilization.

These findings underscore the complex and multifaceted nature of renewable energy adoption, emphasizing the critical role of region-specific economic and policy environments. Understanding these regional disparities is essential for designing effective policies that maximize the utilization of non-hydro renewable energy and contribute to sustainable development goals. The analysis suggests that while urbanization can be a powerful driver of renewable energy adoption, its effectiveness depends on the specific regional context and accompanying policy measures.

The study highlights the significant role of HC in enhancing NHREC across different regions in China, with varying degrees of impact (see Table 9). In the central region, HC significantly contributes to NHREC, with a coefficient of 107.8 ($p < 0.01$). This suggests that substantial investments in education, skills, and innovation create a favorable environment for adopting renewable energy. The model's high R^2 value of 0.983 indicates a strong explanatory power, emphasizing the importance of human capital in this region.

Table 9. Heterogeneity test on the relationship between HC and NHREC.

Region	**Eastern**	**Central**	**Western**	**Northeastern**
Variable		**NHREC**		
HC	3.208 (15.23)	107.8 *** (33.58)	12.85 (26.83)	14.33 (33.07)
Control	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
R^2	0.971	0.983	0.863	0.993
Number of Provinces	10	6	12	3

Note: Standard errors are in parentheses. *** $p < 0.01$.

In contrast, the eastern region shows a non-significant HC coefficient of 3.208, indicating minimal marginal effects of additional human capital investments on renewable energy consumption, likely due to its already advanced economic and technological development. Despite a high R^2 value of 0.971, the established infrastructure and economic base in this region mean that further human capital investment yields limited benefits.

The western region also presents a non-significant HC coefficient of 12.85. This may be due to slower economic development and weaker infrastructure, which limit the effectiveness of human capital in driving renewable energy consumption. The R^2 value of 0.86 suggests that other factors better explain NHREC variance, indicating a need for improved infrastructure and economic policies to complement human capital development.

Similarly, the northeastern region shows a non-significant HC coefficient of 14.33, possibly due to economic challenges, industrial decline, and insufficient policy support. Although the model fits well, indicated by a high R^2 value of 0.99, human capital alone does not significantly drive NHREC in this region.

The analysis emphasizes the need for region-specific strategies to promote renewable energy through human capital investments. In the central region, targeted policies that promote education, skills development, and innovation can significantly enhance renewable energy utilization. This region's success demonstrates that improving human capital quality and availability can lead to substantial advances in renewable energy deployment and efficiency.

In contrast, the eastern region, with its advanced infrastructure, may require policies focused on optimizing existing human capital and exploring new areas of innovation, such as cutting-edge research and emerging technologies. For the western and northeastern regions, enhancing infrastructure, economic incentives, and policy support could make human capital investments more effective in boosting renewable energy consumption. These areas might benefit from improving vocational training, enhancing educational institutions, and incentivizing skilled professionals to work locally.

The findings underscore the importance of understanding regional disparities and tailoring policies to maximize the potential of human capital in promoting renewable energy consumption. The study reveals that while human capital is crucial, its impact varies significantly across regions, necessitating customized approaches to meet each region's specific economic and policy needs. This approach will help achieve China's sustainable development goals, emphasizing the need for diversified and regionally tailored policies to optimize the use of renewable energy resources. Zhou et al. [8] suggest that reducing transmission capacity could promote the development of regional power advantages, such as wind power in the northwest and solar photovoltaics in the southern regions, with respective growth rates of 36.33% and 132.59%.

5. Mechanism Analysis and Discussion

5.1. Mechanism Analysis

Mechanism analysis is a crucial approach for understanding the internal mechanisms among variables, providing researchers with deeper insights into economic and social phenomena. This study employs mechanism analysis to explore how RDI, UR, and HC affect NHREC, specifically focusing on the moderating roles of IS and TA. Moderation effects are a central aspect of this analysis, favored for their flexibility, capacity to reveal complex relationships, and ability to improve model accuracy. Moderation effects are particularly useful because they can be applied across various research contexts and accommodate different types of data and variables. They not only explain variations in the relationship between independent and dependent variables but also reveal how these relationships change across different contexts.

Key benefits of moderation effect analysis include (1) flexibility: This method is adaptable to diverse research scenarios, accommodating various data types and variables. It helps to clarify how the relationship between independent and dependent variables may vary under different conditions. (2) Revealing complex relationships: Many relationships between variables are non-linear and context-dependent. Moderation effects help identify and explain these complexities, offering a more nuanced understanding of the mechanisms at play. (3) Explaining variable interactions: This analysis highlights how different variables interact, which is crucial in practical studies. For instance, different policies might yield varied outcomes depending on the economic environment. Moderation effects can effectively capture and explain these interactions, providing insights into how and why these differences occur. (4) Enhancing model accuracy: Including moderation variables in the analysis can reduce omitted variable bias, thereby increasing the explanatory power and predictive accuracy of the models. This approach offers a more comprehensive description of real-world phenomena, enhancing the practical applicability of the findings.

Table 10 presents the mechanism test results, highlighting the moderating effect of IS on the relationships between RDI, UR, HC, and the NHREC. The interaction terms—IA_1 (RDI × IS), IA_3 (UR × IS), and IA_5 (HC × IS)—are significant, indicating that IS plays a crucial role in moderating these relationships. The coefficient for IA_1 is -9.466, significant at the 1% level. This negative moderating effect suggests that in regions with a concentrated industrial structure, the benefits of increased R&D intensity on NHREC are diminished. In areas where industry is highly concentrated, resource allocation for R&D may be constrained, reducing the effectiveness of R&D efforts in promoting renewable energy consumption.

The coefficient for IA_3 is -1.907, significant at the 5% level. This indicates a negative moderating effect of IS on the relationship between UR and NHREC. High-density industrial clusters in urbanizing regions might lead to intensified resource competition, which can hinder the efficiency of renewable energy adoption and utilization. The coefficient for IA_5 is -27.02, significant at the 10% level. This suggests that in regions with higher levels of human capital, the slow pace of industrial structure adjustment negatively impacts NHREC. Even with a skilled workforce, if the industrial structure is not evolving rapidly enough to support renewable energy technologies, the overall efficiency of renewable energy consumption can be limited.

The study's findings highlight significant negative coefficients for the interaction terms, revealing crucial insights into how IS moderates the effects of RDI, UR, and HC on NHREC. The significant negative interaction between RDI and IS suggests that regions with concentrated industrial structures may struggle to fully capitalize on increased R&D investments. These regions may face difficulties reallocating resources toward renewable energy technologies, limiting the positive impact of R&D. Policies in such regions should prioritize diversifying industrial structures to optimize the benefits of R&D investments, as diverse industrial structures facilitate better integration and utilization of new technologies, enhancing overall energy efficiency.

Table 10. Mechanism analysis on the moderating effects of IS.

	(22)	**(23)**	**(24)**
Variable		NHREC	
RDI	29.72 *** (6.787)	-	-
UR	-	2.881 (1.983)	-
HC	-	-	32.58 ** (13.39)
IS	0.247 (0.151)	0.600 *** (0.202)	0.427 ** (0.202)
IA_1	−9.466 *** (2.754)	-	-
IA_3	-	−1.907 ** (0.856)	-
IA_5	-	-	−27.02 * (14.13)
Control	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
R^2	0.900	0.896	0.894

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The negative interaction between UR and IS indicates that urbanization alone is insufficient to increase renewable energy consumption if industrial structures are inflexible. In urbanizing regions with high industrial density, competition for resources may undermine the efficiency gains from renewable energy technologies. Therefore, it is crucial to manage industrial density and promote balanced urban–industrial development. Urban planning that integrates renewable energy considerations can mitigate the adverse effects of high industrial density, enabling smoother integration of renewable energy systems into the urban environment.

The negative interaction between HC and IS shows that even with high human capital, stagnant industrial structures can hinder renewable energy consumption. Regions with advanced human capital need adaptable industrial structures that support the integration of renewable energy technologies. Accelerating industrial adjustment in line with technological advancements and the capability of skilled labor is essential. Policies that encourage industrial innovation and flexibility will allow regions to fully leverage their human capital to drive renewable energy adoption. Choubineh et al. [52] developed a generation expansion planning model focused on flexibility, which improves the power system's adaptability to renewable energy by considering enhanced reserve requirements. This model underscores the importance of flexibility in adapting to renewable energy sources.

The mechanism test results underscore the critical role of industrial structure in moderating the impacts of RDI, UR, and HC on NHREC. While increased R&D intensity, urbanization, and human capital generally promote renewable energy consumption, the efficiency of these factors is significantly influenced by the region's industrial structure. Concentrated and rigid industrial structures can hinder the positive impacts of these variables on renewable energy consumption. Therefore, policies promoting renewable energy should not only enhance R&D, urbanization, and human capital but also foster adaptable and diversified industrial structures to maximize these investments' benefits. Understanding these dynamics is crucial for designing effective regional strategies that promote sustainable energy consumption and support overall economic development goals. Policies promoting industrial diversification and flexibility will enable regions to better integrate renewable energy technologies, improving overall energy efficiency and sustainability. Additionally, aligning human capital development with industrial needs will further enhance the capacity for renewable energy adoption, creating a robust framework for achieving sustainable development objectives.

Table 11 presents the mechanism test results, highlighting the moderating effect of TA on the relationships between RDI, UR, HC, and NHREC.

Table 11. Mechanism analysis on the moderating effects of TA.

	(25)	**(26)**	**(27)**
Variable		**NHREC**	
RDI	22.88 *** (6.553)	-	-
UR	-	7.291 *** (2.016)	-
HC	-	-	25.30 * (14.61)
TA	3.317 (2.276)	4.847 * (2.605)	6.952 *** (2.565)
IA_2	7.988 (79.18)	-	-
IA_4	-	−28.25 ** (10.99)	-
IA_6	-	-	−470.4 ** (205.4)
Control	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
R^2	0.895	0.896	0.896

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In Model (25), the interaction term IA_2 (RDI × TA) is not significant. This indicates that the moderating effect of TA on the relationship between RDI and NHREC is not apparent in the current sample. The lack of significance suggests that tax does not significantly alter the impact of RDI on renewable energy consumption. It is possible that other overriding factors or the relatively stable RDI across regions play a more crucial role in this context.

In Model (26), the interaction term IA_4 (UR × TA) is significant and negative, with a coefficient of -28.25 ($p < 0.05$). This negative moderating effect suggests that higher taxes diminish the positive impact of urbanization on NHREC. In regions with higher taxes, urbanization might not effectively translate into increased renewable energy consumption due to financial constraints and reduced incentives for investments in renewable energy infrastructure. This is particularly relevant in the central region, where urbanization's positive effects are hindered by high taxes, highlighting the need for tax policies that do not stifle urban development and renewable energy investments.

In Model (27), the interaction term IA_6 (HC × TA) is significant and negative, with a coefficient of -470.4 ($p < 0.05$). This substantial negative effect indicates that higher taxes significantly reduce the positive impact of human capital on NHREC. High taxes may limit the ability of regions to invest in and leverage their human capital for renewable energy projects. The financial strain caused by high taxes can prevent the effective utilization of a skilled workforce, reducing the overall efficiency and impact of human capital on renewable energy adoption. This finding emphasizes the importance of creating favorable tax environments that enable regions to fully leverage their human capital for renewable energy projects.

The analysis reveals that tax plays a crucial moderating role in the effectiveness of RDI, UR, and HC on NHREC. While the interaction between RDI and tax is non-significant, indicating that RDI's effect on renewable energy consumption is relatively stable across varying tax levels, this could suggest that the benefits of RDI in promoting renewable energy are resilient to changes in tax policies. This resilience may be due to RDI's inherent value and effectiveness, which could overshadow the impact of tax variations.

The significant negative interaction between UR and TA suggests that higher taxes can negate the positive effects of urbanization on renewable energy consumption. Urban areas with high taxes may face financial challenges that restrict investments in renewable energy infrastructure, thereby reducing the potential benefits of urbanization on NHREC. This finding highlights the need for balanced tax policies that support urban development and encourage renewable energy investments. To maximize the positive effects of urbanization on NHREC, it is essential to implement tax incentives that foster the growth of renewable energy projects in urban settings.

Similarly, the significant negative interaction between HC and TA underscores the detrimental impact of high taxes on the benefits of human capital for renewable energy consumption. Regions with high taxes may struggle to utilize their skilled workforce effectively due to financial constraints, limiting the role of human capital in advancing renewable energy adoption. This finding stresses the importance of favorable tax environments that allow regions to fully exploit their human capital for renewable energy initiatives. Tax relief and incentives aimed at human capital investment can enhance the skills and capabilities necessary for driving renewable energy projects.

The results from the mechanism test highlight the significant role of tax in moderating the relationships between RDI, UR, HC, and NHREC. Although RDI, UR, and HC generally promote renewable energy consumption, their effectiveness is significantly affected by the regional tax. High taxes can reduce the positive impacts of these factors on NHREC, emphasizing the need for supportive tax policies that encourage renewable energy investments and human capital development.

Regions facing high taxes may benefit from tax reforms aimed at alleviating financial constraints and promoting investments in renewable energy infrastructure and human capital development. Understanding the complex interactions between these factors is essential for crafting effective policies that promote sustainable energy consumption and support broader economic development goals. These findings underscore the critical role of tax policies in enhancing renewable energy adoption and utilization. By addressing the moderating effects of tax, policymakers can foster an environment that maximizes the benefits of RDI, UR, and HC, thus advancing progress toward sustainable energy solutions and economic growth.

5.2. Discussion

The primary objective of this research is to analyze the key factors influencing the NHREC across 31 provincial regions in China. The study employs fixed effects and moderating effects to examine the impacts of RDI, UR, and HC on NHREC. Additionally, it considers IS and TA as moderating variables, with control variables such as IN and ED (see Table 12).

The results align with the initial hypotheses, demonstrating the significant roles of RDI, UR, and HC in promoting NHREC. Specifically, the findings indicate that (1) the regression analysis reveals a robust positive relationship between RDI and NHREC. RDI significantly enhances NHREC, underscoring the importance of technological advancements and innovation in the renewable energy sector. However, in regions with concentrated industrial structures, the benefits of increased RDI are diminished due to constrained resource allocation for R&D activities. (2) UR significantly boosts NHREC, particularly in rapidly urbanizing regions such as the central region. The positive impact of UR is linked to improved infrastructure and increased economic activities that facilitate renewable energy adoption. However, high taxes can reduce the positive impact of UR on NHREC by creating financial constraints that limit investments in renewable energy infrastructure. (3) HC positively influences NHREC by providing a skilled and educated workforce capable of driving renewable energy projects. The central region benefits the most from human capital investments, suggesting that policies promoting education, skills development, and innovation are crucial for renewable energy utilization. High taxes, however, can significantly reduce the positive impact of HC on NHREC by limiting the financial resources necessary for leveraging human capital effectively.

Table 12. Hypotheses and results summary.

Hypothesis	Supported (Yes/No)	Explanation
H_1	Yes	RDI has a strong positive effect on NHREC, emphasizing the role of technological innovation in promoting renewable energy consumption.
H_2	Yes	UR significantly boosts NHREC, particularly in the central region, where urbanization leads to better infrastructure and economic activities that favor renewable energy adoption.
H_3	Yes	HC enhances NHREC by providing the necessary skilled workforce for renewable energy projects, with the strongest impact in the central region, highlighting the importance of human capital.
H_4	Yes	IS moderates the RDI-NHREC relationship, with concentrated industrial structures reducing the positive impact of RDI due to resource constraints.
H_5	Yes	IS negatively affects the UR-NHREC relationship, as industrial clusters in urban areas increase resource competition, reducing renewable energy efficiency.
H_6	Yes	IS negatively moderates the HC-NHREC relationship, as slow industrial changes in high-human-capital regions limit the effectiveness of human capital on renewable energy consumption.
H_7	No	TA does not significantly impact the RDI-NHREC relationship, indicating that tax does not alter the influence of RDI on renewable energy consumption.
H_8	Yes	TA negatively affects the UR-NHREC relationship, with higher taxes limiting investments in renewable energy infrastructure by creating financial constraints.
H_9	Yes	TA negatively moderates the HC-NHREC relationship, as high taxes limit financial resources, reducing the positive impact of human capital on renewable energy adoption.

The study investigates the moderating effects of IS and TA on the relationships between RDI, UR, HC, and NHREC. The findings indicate that IS significantly moderates the effects of RDI, UR, and HC on NHREC. In regions with highly concentrated industrial structures, the positive impacts of these factors are diminished, highlighting the necessity for diversified industrial structures to optimize the benefits of RDI, UR, and HC in advancing renewable energy. TA also plays a crucial moderating role; higher taxes negatively impact the relationships between UR, HC, and NHREC, suggesting that balanced tax policies are essential to support renewable energy investments.

The study's results align with previous research in several areas while also presenting new insights due to regional and contextual variations. The positive impact of RDI on NHREC is consistent with findings by Ma et al. [39] and Lin and Shi [21], emphasizing the critical role of technological innovation in renewable energy adoption. RDI fosters innovation, leading to technological advancements that reduce costs and improve the efficiency of renewable energy technologies, thereby enhancing their attractiveness.

Urbanization's significant role is corroborated by Liu and Feng [19], who discuss the influence of urbanization on energy demand and renewable energy adoption. Urbanization leads to improved infrastructure, increased economic activities, and higher energy demands, creating a conducive environment for integrating renewable energy solutions.

The study also confirms the positive effect of HC on renewable energy consumption which highlights the importance of skilled labor in enhancing renewable energy projects. High levels of human capital ensure a skilled workforce capable of implementing, managing, and innovating within the renewable energy sector, thus driving greater adoption.

The study presents a nuanced understanding of IS's moderating effect, which is not extensively covered in the previous literature. While Lin and Omoju [40] acknowledge the role of financial development facilitated by a skilled workforce in renewable energy adoption, the specific negative moderating role of IS on NHREC emphasizes the complexity of these relationships. In regions with concentrated industrial structures, resource allocation for R&D may be constrained, reducing the effectiveness of R&D efforts in promoting renewable energy consumption. This finding suggests a need for diversified industrial structures to optimize the benefits of R&D investments.

The study also provides new insights into the moderating effect of TA. The existing literature often overlooks the direct impact of tax policies on renewable energy adoption. This study finds that higher taxes can diminish the positive impacts of urbanization and human capital on NHREC by creating financial constraints and reducing investment incentives. High taxes can limit the financial resources available to both individuals and businesses, discouraging investments in renewable energy infrastructure and human capital development.

These findings carry profound economic implications. The consistent positive impacts of RDI, UR, and HC on NHREC underscore the crucial roles of technological innovation, urbanization, and skilled labor in promoting renewable energy adoption. Investments in R&D lead to technological advancements, reducing costs and increasing efficiency. Urbanization fosters economic growth and infrastructure development, supporting renewable energy integration. Human capital ensures a steady supply of skilled professionals capable of implementing and optimizing renewable energy solutions.

However, the negative moderating effects of IS and TA highlight the challenges posed by industrial concentration and high taxes. Concentrated industrial structures can limit the benefits of R&D investments by constraining resource allocation, while high taxes can create financial barriers that reduce the effectiveness of urbanization and human capital in promoting renewable energy consumption. These factors emphasize the need for integrated policies that enhance R&D capabilities, support sustainable urbanization, and invest in human capital while fostering adaptable industrial structures and balanced tax policies.

Understanding regional disparities and the complex interactions between various factors is crucial for designing effective strategies to optimize the use of NHRE and support China's sustainable development goals. The findings from this study provide valuable insights for policymakers and researchers, emphasizing the importance of region-specific policies that consider economic and infrastructural conditions. Tian et al. [24] suggest that utilizing local wind and solar resources can meet NHRE quota standards in the short to medium term, reducing the urgency for long-distance transmission line construction. However, in the long term, constructing adequate transmission lines is critical for a nationwide carbon-neutral power system. According to Zhao et al. [25], an optimized renewable portfolio standard scheme increases quotas for most provinces, with economically developed provinces sharing the responsibility for renewable electricity production. This scheme leads to a 43.8% increase in NHRE generation, an 18.4% increase in profits for NHRE producers, and a 27.9% reduction in environmental pollution costs.

The study underscores the importance of tailored regional policies that support R&D, sustainable urbanization, and human capital development while promoting adaptable and diversified industrial structures. Balanced tax policies are essential to minimize financial constraints and encourage investments in renewable energy infrastructure and human capital. These insights are critical for achieving China's carbon neutrality goals by 2060, promoting environmental sustainability and economic resilience.

The economic implications of these findings are significant. Investments in R&D stimulate technological innovation and create a conducive environment for the diffusion of advanced renewable energy technologies, reducing costs and increasing efficiency. Sustainable urbanization drives economic growth and infrastructure development, facilitating renewable energy integration. Human capital development ensures a steady supply of skilled professionals capable of implementing and optimizing renewable energy solutions. Integrated policies that enhance R&D capabilities, support sustainable urbanization, and invest in human capital will synergistically promote renewable energy adoption and utilization, leading to economic growth, job creation, and environmental benefits. Addressing the moderating effects of industrial structure and tax is crucial for creating an environment that maximizes the benefits of RDI, UR, and HC, driving progress toward sustainable energy solutions and economic growth.

To foster a conducive environment for the adoption and utilization of renewable energy, tailored policy recommendations for the government, enterprises, and individuals are necessary. The proposed policy recommendations are designed to enhance the adoption of NHRE in China. The feasibility of these policies is assessed based on the current economic, technological, and regulatory landscape. For instance, creating 'Renewable Energy Innovation Hubs' is feasible given China's strong focus on technological innovation and the existing infrastructure for research and development. Developing 'Solar Cities' aligns with China's urbanization goals and the increasing investments in solar energy. The 'Carbon Offset Lottery' can be implemented as part of China's broader efforts to incentivize green investments.

Several potential barriers could impede the implementation of these policies. Financial constraints, such as limited access to funding for renewable energy projects, could hinder progress. Technological limitations, including the availability and scalability of renewable energy technologies, present another challenge. Regulatory hurdles, such as bureaucratic delays and fragmented policy frameworks, can slow down implementation. Additionally, public acceptance issues, driven by a lack of awareness or resistance to change, may pose significant obstacles. To overcome financial constraints, it is essential to foster public–private partnerships and seek international funding opportunities. Increasing investment in R&D and promoting collaborations between academic institutions and the private sector can address technological limitations. Streamlining regulatory processes and enhancing coordination among government agencies can mitigate regulatory hurdles. Public acceptance issues can be addressed through comprehensive awareness campaigns and active community engagement, ensuring that the benefits of renewable energy adoption are clearly communicated to the public.

The government should enhance support for R&D by allocating more resources to foster innovation in renewable energy technologies, providing tax credits, grants, and subsidies for companies investing in renewable energy R&D. Establishing "Renewable Energy Innovation Hubs" in underdeveloped regions and promoting sustainable urbanization through investments in modern infrastructure are critical steps. Urban planning policies should prioritize renewable energy projects, such as solar panel installations on buildings and green public transportation systems. The concept of "Solar Cities", which mandates solar panels on new buildings and retrofits old buildings with renewable energy solutions, could significantly boost renewable energy adoption. Handayani et al. [12] suggest that developing countries should focus on investing in energy storage systems and infrastructure to support high proportions of renewable energy integration, with annual costs on a sustainable path estimated at 1.1% to 1.8% of 2020 GDP.

For enterprises, the emphasis should be on investing in R&D and adopting renewable energy solutions within their operations. Implementing energy-efficient practices and promoting workforce development are crucial for contributing to the renewable energy transition. Enterprises should establish internal R&D departments, collaborate with academic institutions, and adopt innovative renewable energy technologies. Engaging in corporate social responsibility initiatives, such as integrating sustainability into corporate strategies and promoting renewable energy awareness within local communities, is also vital.

For individuals, the study highlights the importance of adopting renewable energy solutions at home and participating in community-based renewable energy initiatives. Informed choices, such as investing in solar panels or home wind turbines, can significantly reduce carbon footprints and support the broader transition to renewable energy. Participating in educational programs to stay informed about the latest renewable energy technologies and advocating for policies that support renewable energy adoption are essential actions for individuals.

Human capital development is a critical area for governmental focus in advancing renewable energy industries. Governments should establish specialized programs in universities and vocational institutions to equip the workforce with necessary skills. Providing incentives such as competitive salaries and career advancement opportunities for skilled professionals in the renewable energy sector is essential. Additionally, initiatives like "Green Scholarships" for students pursuing renewable energy degrees, funded by a green tax on non-renewable energy companies, can support this goal. Tax reforms should aim to alleviate financial burdens on renewable energy investments while ensuring government revenue. Offering tax deductions and credits for businesses and individuals investing in renewable energy technologies, alongside innovative approaches like a "Carbon Offset Lottery" for taxpayers investing in renewable projects, can encourage green investments.

Diversifying industrial structures is also crucial. Governments should promote diversification by supporting emerging industries aligned with renewable energy objectives and fostering the development of industrial clusters focused on renewable technologies. Establishing "Green Industrial Parks" dedicated to renewable energy businesses, with incentives such as reduced utility rates and property taxes, can stimulate collaboration and innovation.

Enterprises play a significant role in the transition to renewable energy. They should invest in R&D by creating or expanding internal departments focused on developing new renewable technologies and collaborate with academic and research institutions. Implementing "Open Innovation Platforms" can encourage employees and external innovators to propose new renewable energy solutions with company funding. Additionally, companies should transition to renewable energy for their operations and adopt energy-efficient practices. Initiatives like the "Green Power Purchase Program" allow companies to buy renewable energy directly from local producers, ensuring a stable and clean energy supply.

Workforce development within enterprises is also vital. Continuous training programs should be provided to enhance employees' skills in renewable energy technologies, fostering a culture of innovation and sustainability. Programs like the "Employee Green Innovator" reward employees for developing sustainable practices within the company. In terms of corporate social responsibility, companies should integrate sustainability into their strategies, report on renewable energy usage, engage local communities to promote awareness, and establish "Community Solar Farms" to provide residents with access to renewable energy.

Individuals can contribute by adopting renewable energy solutions such as solar panels and wind turbines to reduce personal carbon footprints. Implementing energy-saving measures at home and participating in "Neighborhood Renewable Energy Co-ops" can enhance community engagement. Individuals should also engage in educational programs to stay informed about renewable technologies and consider pursuing qualifications in renewable energy fields. "Green Living Certifications" can provide credentials in sustainable living practices.

Advocacy for policy changes is another critical area for individuals. Engaging in local advocacy, voting for pro-renewable energy representatives and policies, and joining or forming "Green Advocacy Groups" can influence policy changes favoring renewable initiatives. Supporting renewable energy businesses, investing in renewable projects and companies, and using "Green Investment Platforms" for small-scale investments in renewable startups can democratize access to sustainable investments and foster a greener economy.

6. Conclusions and Policy Implications

The analysis of the determinants of non-hydro renewable energy consumption (NHREC) across 31 provincial regions in China provides critical insights into the factors driving renewable energy adoption. The urgency to address climate change and China's commitment to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060 underscore the importance of this study. This research seeks to understand the influences of research and development intensity (RDI), urbanization (UR), and human capital (HC) on NHREC, considering the moderating roles of industrial structure (IS) and taxation (TA) and including control variables such as informationization (IN) and economic development (ED).

The study employs fixed effects and moderating effect methodologies, using data from 2015 to 2022 sourced from the China Statistical Yearbook and other authoritative reports. The findings reveal a strong positive relationship between RDI and NHREC, indicating that increased investment in R&D enhances technological advancements, reducing the costs and improving the efficiency of renewable energy technologies. UR is also found to significantly boost NHREC, particularly in rapidly urbanizing regions, by driving demand through increased economic activities, population density, and infrastructure development. Additionally, HC positively influences NHREC, highlighting the importance of a skilled and educated workforce in advancing renewable energy projects, with notable benefits observed in the central region.

The study also uncovers that IS moderates the effects of RDI, UR, and HC on NHREC, where regions with concentrated industrial structures face reduced positive impacts due to resource allocation constraints. High taxes negatively affect the relationships between UR, HC, and NHREC, creating financial barriers that hinder investments in renewable energy infrastructure and human capital development.

These determinants and models are applicable to other developing countries, though local adjustments would be necessary. RDI universally drives technological innovation, enhancing efficiency and reducing costs of renewable energy technologies. However, the foundation and policy support for RDI may differ, necessitating adjustments in R&D policies and funding based on the specific context of each country. Urbanization increases energy demand and infrastructure improvement globally, leading to a rise in renewable energy demand in rapidly urbanizing regions. Local urban planning and energy policies must account for variations in the speed and pattern of urbanization across countries.

Human capital is crucial for advancing renewable energy projects. Other developing countries can enhance education and training to support renewable energy development, though tailored plans are required to address different levels of investment in education and training outcomes. The impacts of industrial structure and tax policies on renewable energy consumption are universally applicable. An appropriate industrial structure and favorable tax policies promote renewable energy development. However, adjustments are needed according to each country's economic structure and tax system.

The paper found that the identified determinants—RDI, UR, and HC—exhibit varying impacts across regions and contexts. While each determinant positively influences NHREC, the magnitude and significance of these effects depend on regional factors such as economic development, industrial structure, and local policy environments. The importance of regional analysis is emphasized in understanding these varying impacts. RDI tends to have a more substantial effect in regions with higher levels of industrialization, whereas UR is more influential in rapidly urbanizing areas where infrastructure development is prioritized. Similarly, HC's impact is more pronounced in regions with a higher concentration of skilled labor and educational institutions. The discussion section has been updated to reflect this nuanced understanding, incorporating specific examples from the empirical results.

Policy recommendations from the study emphasize the need for government support in R&D through funding, tax credits, and subsidies. Sustainable urbanization should be promoted by investing in infrastructure and green urban planning. Additionally, developing human capital through specialized programs and incentives for skilled professionals is crucial. The study also suggests implementing balanced tax policies to alleviate financial burdens on renewable energy investments and supporting industrial diversification by encouraging the growth of industries focused on renewable energy technologies.

Enterprises are encouraged to invest in R&D, adopt renewable energy solutions, and engage in corporate social responsibility by integrating sustainability into their strategies. Continuous training for employees and promoting sustainable practices are also recommended. For individuals, the study advocates for adopting renewable energy solutions at home, participating in community-based renewable energy initiatives, engaging in educational programs, and supporting companies committed to sustainability.

Theoretical contributions of this study include an expanded framework highlighting the roles of RDI, UR, and HC in promoting NHREC. The study's examination of the moderating effects of IS and TA provides a nuanced understanding of the complex interactions influencing renewable energy adoption, integrating considerations of industrial and fiscal policies. The comprehensive analytical framework offers a robust model for future research on the determinants of renewable energy consumption, contributing significantly to the literature.

The study provides significant practical implications for various stakeholders, offering strategic guidance to policymakers, enterprises, and individuals regarding NHREC. Policymakers are advised to support research and development (R&D), promote sustainable urbanization, and invest in human capital to enhance NHREC. The development of tailored regional policies, considering specific economic and infrastructural conditions, is crucial. Government initiatives should focus on increasing R&D funding; sustainable urban planning, education, and training programs; and implementing balanced tax policies to mitigate financial challenges associated with renewable energy investments.

For enterprises, this study emphasizes the necessity of investing in R&D and adopting renewable energy solutions in operational processes. Companies should focus on energy efficiency, establish R&D departments, collaborate with academic institutions, and incorporate innovative renewable energy technologies. Additionally, corporate social responsibility should include integrating sustainability into business strategies and raising awareness about renewable energy in local communities.

Individuals are encouraged to adopt renewable energy solutions in their households and participate in community-based renewable energy initiatives. By making informed choices, such as installing solar panels or wind turbines, individuals can contribute to reducing their carbon footprint. The study also highlights the importance of engaging in educational programs to stay updated on renewable energy technologies and advocating for supportive policies.

The study identifies several limitations that may influence the results and suggests potential areas for future research. First, the reliance on data from 2015 to 2022, sourced from the China Statistical Yearbook and other authoritative reports, raises concerns about data accuracy and completeness, potentially leading to biased results. Second, the focus on 31 provincial regions in China, each with unique economic, social, and infrastructural characteristics, may limit the generalizability of the findings to other regions or countries. Third, the relatively short time frame may not capture long-term trends or the impact of recent policy changes and technological advancements in renewable energy. Fourth, the exclusion of other potentially influential factors, such as environmental regulations, international trade policies, or social acceptance of renewable energy, may result in an incomplete understanding of the factors affecting NHREC. Fifth, the study is limited by the absence of qualitative research methods, such as interviews or case studies. This absence restricts a deeper understanding of the nuanced contextual factors and stakeholders' perspectives influencing NHRE adoption. Finally, while the study uses robust statistical methods, establishing causality between the determinants and NHREC remains challenging due to potential reverse causality or omitted variable bias [53–55].

Future studies should consider extending the time frame to include more recent and longer historical data to capture long-term trends and recent developments in NHREC. This approach would help in understanding the evolving dynamics of renewable energy adoption. Additionally, exploring additional moderating variables such as environmental regulations, international trade policies, and social acceptance can provide a more comprehensive understanding of the determinants influencing NHREC. These factors are crucial for assessing how external and contextual influences shape renewable energy consumption.

Comparative studies across different countries or regions with varying economic, social, and policy contexts can help generalize the findings and identify both universal and context-specific determinants of NHREC. Such studies would be valuable in drawing parallels and contrasts between different geopolitical and economic environments, providing insights into the adaptability and scalability of policy measures.

Employing longitudinal analysis methods can establish causal relationships between the determinants and NHREC, accounting for time-varying effects and providing robust evidence. This methodology can help identify the long-term impacts of different variables on renewable energy consumption, distinguishing between short-term fluctuations and sustained trends.

Additionally, investigating the impact of specific policy changes on NHREC can offer valuable insights for policymakers. Understanding how policies such as subsidies, tax incentives, and regulatory frameworks influence renewable energy adoption can guide the design of more effective policy interventions. Exploring the role of technological advancements and innovations in driving NHREC is also critical, as technological progress can significantly alter the cost and efficiency landscape of renewable energy technologies.

Conducting micro-level analyses, such as household or firm-level studies, can provide detailed insights into the adoption and consumption patterns of NHREC, identifying barriers and facilitators at the individual or organizational level. These analyses are crucial for understanding the microeconomic and behavioral factors that drive renewable energy decisions, offering a granular view of the challenges and opportunities in the sector.

Future research should integrate qualitative approaches, such as in-depth interviews, focus groups, and case studies, to provide a more holistic view of the challenges and opportunities in the NHRE sector. These methods can uncover barriers and enablers not evident through quantitative analysis alone, providing richer, context-specific insights into the sociocultural and policy factors affecting NHREC. Such approaches are recommended to deepen the understanding of the complex interplay between various determinants of renewable energy adoption, offering a comprehensive view of the factors influencing the transition to sustainable energy systems.

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References

1. Pfeiffer, B.; Mulder, P. Explaining the diffusion of renewable energy technology in developing countries. *Energy Econ.* **2013**, *40*, 285–296. [CrossRef]
2. Jiang, X.; Wang, H.; Xia, Y. Economic structural change, renewable energy development, and carbon dioxide emissions in China. *Mitig. Adapt. Strat. Glob. Chang.* **2020**, *25*, 1345–1362. [CrossRef]
3. Marques, A.C.; Fuinhas, J.A.; Pereira, D.S. The dynamics of the short and long-run effects of public policies supporting renewable energy: A comparative study of installed capacity and electricity generation. *Econ. Anal. Policy* **2019**, *63*, 188–206. [CrossRef]
4. Ma, Y.; Wang, Y.; Zhou, X. The impact of green finance on the development of the non-hydro renewable energy industry: An empirical study based on data from 30 provinces in China. *Renew. Energy* **2024**, *227*, 120543. [CrossRef]
5. Zhao, K.-X.; Xu, F.-R.; Zhou, Y.; Ma, T. The heterogeneous effects of non-hydro renewable energy and water resources on industrial development of the yellow river and yangtze river basins. *Energy* **2024**, *301*, 131736. [CrossRef]
6. Diniz, T.B.; Couto, L.C. Achieving a high share of non-hydro renewable integration in Brazil through wind power: Regional growth and employment effects. *Renew. Sustain. Energy Rev.* **2024**, *197*, 114367. [CrossRef]
7. Yu, S.; Zheng, Y.; Hu, X. How does climate change affect firms' investment efficiency? Evidence from China's listed renewable energy firms. *Bus. Strat. Environ.* **2023**, *32*, 3977–3996. [CrossRef]
8. Zhou, S.; Yang, J.; Yu, S. A Stochastic Multi-Objective Model for China's Provincial Generation-Mix Planning: Considering Variable Renewable and Transmission Capacity. *Energies* **2022**, *15*, 2797. [CrossRef]
9. Trotter, P.A. The slow transition to solar, wind and other non-hydro renewables in Africa—Responding to and building on a critique by Kincer, Moss and Thurber (2021). *World Dev. Perspect.* **2022**, *25*, 100376. [CrossRef]

10. Seriño, M.N.V. Energy security through diversification of non-hydro renewable energy sources in developing countries. *Energy Environ.* **2022**, *33*, 546–561. [CrossRef]
11. Varga, G.; Gresina, F.; Szeberényi, J.; Gelencsér, A.; Rostási, Á. Effect of Saharan dust episodes on the accuracy of photovoltaic energy production forecast in Hungary (Central Europe). *Renew. Sustain. Energy Rev.* **2024**, *193*, 114289. [CrossRef]
12. Handayani, K.; Overland, I.; Suryadi, B.; Vakulchuk, R. Integrating 100% renewable energy into electricity systems: A net-zero analysis for Cambodia, Laos, and Myanmar. *Energy Rep.* **2023**, *10*, 4849–4869. [CrossRef]
13. Sanchez, R.G.; Seliger, R.; Fahl, F.; De Felice, L.; Ouarda, T.B.; Farinosi, F. Freshwater use of the energy sector in Africa. *Appl. Energy* **2020**, *270*, 115171. [CrossRef]
14. Zhou, X.; Zhao, Q.; Zhang, Y.; Sun, L. Integrated energy production unit: An innovative concept and design for energy transition toward low-carbon development. *CSEE J. Power Energy Syst.* **2021**, *7*, 1133–1139. [CrossRef]
15. Asadi, M.; Larki, I.; Forootan, M.M.; Ahmadi, R.; Farajollahi, M. Long-term scenario analysis of electricity supply and demand in Iran: Time series analysis, renewable electricity development, energy efficiency and conservation. *Sustainability* **2023**, *15*, 4618. [CrossRef]
16. Dukpa, A. Scope for feed-in tariff in a hydro-rich energy market-a case of Bhutan. *Int. J. Energy Environ. Eng.* **2023**, *14*, 613–626. [CrossRef]
17. Chen, X.; Li, Z.; Gallagher, K.P.; Mauzerall, D.L. Financing carbon lock-in in developing countries: Bilateral financing for power generation technologies from China, Japan, and the United States. *Appl. Energy* **2021**, *300*, 117318. [CrossRef]
18. Kim, J.W.; Lee, J.-S. Greening Energy Finance of Multilateral Development Banks: Review of the World Bank's Energy Project Investment (1985–2019). *Energies* **2021**, *14*, 2648. [CrossRef]
19. Liu, Y.; Feng, C. Promoting renewable energy through national energy legislation. *Energy Econ.* **2023**, *118*, 106504. [CrossRef]
20. Yi, B.-W.; Eichhammer, W.; Pfluger, B.; Fan, Y.; Xu, J.-H. The spatial deployment of renewable energy based on China's coal-heavy generation mix and inter-regional transmission grid. *Energy J.* **2019**, *40*, 45–74. [CrossRef]
21. Lin, B.; Shi, L. New understanding of power generation structure transformation, based on a machine learning predictive model. *Sustain. Energy Technol. Assess.* **2022**, *51*, 101962. [CrossRef]
22. Olanrele, I.A.; Fuinhas, J.A. Assessment of renewable electricity adoption in sub-Saharan Africa. *Energy Environ.* **2024**, *35*, 848–873. [CrossRef]
23. Wang, G.; Zhang, Q.; Li, Y.; Mclellan, B.C. Efficient and equitable allocation of renewable portfolio standards targets among China's provinces. *Energy Policy* **2019**, *125*, 170–180. [CrossRef]
24. Tian, J.H.; Zhou, S.; Wang, Y. Assessing the technical and economic potential of wind and solar energy in China: A provincial-scale analysis. *Environ. Impact Assess. Rev.* **2023**, *102*, 107161. [CrossRef]
25. Zhao, X.; Lu, W.; Wang, W.; Hu, S.; Yi, Z. How to optimize allocation of renewable portfolio standards for renewable energy development in China? *J. Renew. Sustain. Energy* **2023**, *15*, 035901. [CrossRef]
26. Gao, Y.; Liu, J.L.; Bashir, S. Electrocatalysts for direct methanol fuel cells to demonstrate China's renewable energy renewable portfolio standards within the framework of the 13th five-year plan. *Catal. Today* **2021**, *374*, 135–153. [CrossRef]
27. Argin, M.; Yerci, V.; Erdogan, N.; Kucuksari, S.; Cali, U. Exploring the offshore wind energy potential of Turkey based on multi-criteria site selection. *Energy Strat. Rev.* **2019**, *23*, 33–46. [CrossRef]
28. Aryanpur, V.; Atabaki, M.S.; Marzband, M.; Siano, P.; Ghayoumi, K. An overview of energy planning in Iran and transition pathways towards sustainable electricity supply sector. *Renew. Sustain. Energy Rev.* **2019**, *112*, 58–74. [CrossRef]
29. Carvajal, P.E.; Li, F.G.N. Challenges for hydropower-based nationally determined contributions: A case study for Ecuador. *Clim. Policy* **2019**, *19*, 974–987. [CrossRef]
30. Johnsson, F.; Kjärstad, J.; Rootzén, J. The threat to climate change mitigation posed by the abundance of fossil fuels. *Clim. Policy* **2019**, *19*, 258–274. [CrossRef]
31. Nguyen, P.A.; Abbott, M.; Nguyen, T.L.T. The development and cost of renewable energy resources in Vietnam. *Util. Policy* **2019**, *57*, 59–66. [CrossRef]
32. Schlachtberger, D.P.; Brown, T.; Schäfer, M.; Schramm, S.; Greiner, M. Cost optimal scenarios of a future highly renewable European electricity system: Exploring the influence of weather data, cost parameters and policy constraints. *Energy* **2018**, *163*, 100–114. [CrossRef]
33. Gonzalez-Salazar, M.; Poganietz, W.R. Evaluating the complementarity of solar, wind and hydropower to mitigate the impact of El Niño Southern Oscillation in Latin America. *Renew. Energy* **2021**, *174*, 453–467. [CrossRef]
34. Kudelin, A.; Kutcherov, V. Wind ENERGY in Russia: The current state and development trends. *Energy Strat. Rev.* **2021**, *34*, 100627. [CrossRef]
35. Fan, J.-L.; Wang, J.-X.; Hu, J.-W.; Yang, Y.; Wang, Y. Will China achieve its renewable portfolio standard targets? An analysis from the perspective of supply and demand. *Renew. Sustain. Energy Rev.* **2021**, *138*, 110510. [CrossRef]
36. Yi, B.-W.; Xu, J.-H.; Fan, Y. Coordination of policy goals between renewable portfolio standards and carbon caps: A quantitative assessment in China. *Appl. Energy* **2019**, *237*, 25–35. [CrossRef]
37. Yang, Y.; Zhang, H.; Xiong, W.; Zhang, D.; Zhang, X. Regional power system modeling for evaluating renewable energy development and CO2 emissions reduction in China. *Environ. Impact Assess. Rev.* **2018**, *73*, 142–151. [CrossRef]
38. Wang, Y.; Shi, R.; Zhang, C.; He, Y.; Jiang, H.; Kubota, J. Structural changes and trends in China's renewable electricity production in the policy evolution process. *Renew. Energy* **2022**, *182*, 879–886. [CrossRef]

39. Ma, Y.; Zhang, T.T.; Qian, W.; Wei, D. Financial development, demographic changes, and the growth of the non-hydro renewable energy industry—An empirical test based on R&D and financing costs. *Renew. Energy* **2022**, *185*, 217–229. [CrossRef]
40. Lin, B.; Omoju, O.E. Focusing on the right targets: Economic factors driving non-hydro renewable energy transition. *Renew. Energy* **2017**, *113*, 52–63. [CrossRef]
41. Xu, J.; Yang, G.; Wang, F.; Shu, K. A provincial renewable portfolio standards-based distribution strategy for both power plant and user: A case study from Guangdong, China. *Energy Policy* **2022**, *165*, 112935. [CrossRef]
42. Saiprasad, N.; Kalam, A.; Zayegh, A. Triple Bottom Line Analysis and Optimum Sizing of Renewable Energy Using Improved Hybrid Optimization Employing the Genetic Algorithm: A Case Study from India. *Energies* **2019**, *12*, 349. [CrossRef]
43. National Bureau of Statistics of China. National Data. 2024. Available online: https://data.stats.gov.cn/easyquery.htm?cn=C01 (accessed on 1 July 2024).
44. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation of the Development of Renewable Energy Electricity for the Year 2015. 2016. Available online: https://zfxxgk.nea.gov.cn/auto87/201608/t20160823_2289.htm (accessed on 1 July 2024).
45. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation of the Development of Renewable Energy Electricity for the Year 2016. 2017. Available online: https://zfxxgk.nea.gov.cn/auto87/201704/t20170418_2773.htm (accessed on 1 July 2024).
46. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation of the Development of Renewable Energy Electricity for the Year 2017. 2018. Available online: https://zfxxgk.nea.gov.cn/auto87/201805/t20180522_3179.htm (accessed on 1 July 2024).
47. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation of the Development of Renewable Energy Electricity for the Year 2018. 2019. Available online: https://www.gov.cn/zhengce/zhengceku/2019-09/29/content_5434697.htm (accessed on 1 July 2024).
48. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation of the Development of Renewable Energy Electricity for the Year 2019. 2020. Available online: https://zfxxgk.nea.gov.cn/2020-05/06/c_139059627.htm (accessed on 1 July 2024).
49. National Energy Administration of China. National Energy Administration's Report on The Monitoring and Evaluation Results of the Development of Renewable Energy Electricity for the Year 2020. 2021. Available online: https://zfxxgk.nea.gov.cn/2021-06/20/c_1310039970.htm (accessed on 1 July 2024).
50. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation Results of the Development of Renewable Energy Electricity for the Year 2021. 2022. Available online: https://www.nea.gov.cn/2022-09/16/c_1310663387.htm (accessed on 1 July 2024).
51. National Energy Administration of China. National Energy Administration's Report on the Monitoring and Evaluation Results of the Development of Renewable Energy Electricity for The Year 2022. 2023. Available online: https://zfxxgk.nea.gov.cn/2023-09/07/c_1310741874.htm (accessed on 1 July 2024).
52. Choubineh, K.; Yousefi, H.; Moeini-Aghtaie, M. Developing a new flexibility-oriented model for generation expansion planning studies of renewable-based energy systems. *Energy Rep.* **2024**, *11*, 706–719. [CrossRef]
53. Becerralopez, H.R.; Golding, P. Dynamic exergy analysis for capacity expansion of regional power-generation systems: Case study of far West Texas. *Energy* **2007**, *32*, 2167–2186. [CrossRef]
54. Li, Z.Q.; Wang, C.X.; Ye, X.N.; Li, Y.Y.; Lei, X.J. Evaluation of renewables portfolio standards trading volume and analysis of influencing factors. In Proceedings of the 2019 Chinese Automation Congress (CAC2019), Hangzhou, China, 22–24 November 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 3897–3900. [CrossRef]
55. Mirzaee, A.; McGarvey, R.G.; Aguilar, F.X.; Schliep, E.M. Impact of biopower generation on eastern US forests. *Environ. Dev. Sustain.* **2023**, *25*, 4087–4105. [CrossRef]