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Renewable Energy Foreign Direct Investment and Global Power Sector Green Transition: Micro-Level Evidence for Sustainable Development

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Abstract

Achieving Sustainable Development Goal (SDG) 7 (clean energy access) and SDG 13 (climate action) requires understanding how international capital shapes national power sector transitions. Yet the role of renewable energy foreign direct investment (FDI) in driving this transformation remains empirically underdeveloped. Using a unique, manually constructed firm-project-level dataset of renewable energy FDI spanning 185 countries over 2003–2023, this study provides novel micro econometric evidence on how cross-border renewable energy investment affects the global power sector. We find that renewable energy FDI significantly increases both the level and share of renewable electricity generation through capital investment and job-creation channels, thereby accelerating the green transition of the power sector. Heterogeneity analysis shows that these effects are strongest for wind and solar power, and more pronounced in high-income economies than in low-income ones. Among project types, expansion and co-location projects generate stronger employment and output effects than new investments, owing to lower marginal costs and faster deployment on existing infrastructure. These findings extend the Pollution Halo Hypothesis to the electricity sector and carry direct implications for global energy governance: high-income countries should sustain green FDI incentives, while developing economies must strengthen institutional and infrastructural conditions to fully capture the sustainable development benefits of international renewable energy investment.

Keywords: Renewable energy; Foreign direct investment; Electricity sector; Green transition; Sustainable development goals

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1. Introduction

Reducing costs, improving environmental quality, and creating new jobs have increased global interest in energy transition—from traditional fossil fuels to renewable energy sources. In recent years, supported by policy incentives, global renewable energy capacity has continued to expand, particularly in wind and solar power. In 2023, global investment in renewable energy reached a record high of USD 622.5 billion, an 8.1% increase over 2022. Global renewable energy capacity additions are projected to increase by 36% to 473 gigawatts, while 130 countries have committed to tripling their renewable energy capacity by 2030 (REN21, 2024). Although cyclical fluctuations in global greenfield investment persist, renewable energy–related greenfield investment is expected to sustain steady growth, driven by technological innovation, policy support, and rising energy demand. Its share of total global greenfield investment is also projected to increase (see Fig. 1). However, the role of international investment in renewable energy has not been sufficiently examined in the existing literature. There is still a lack of rigorous empirical evidence on whether renewable energy FDI can effectively promote the green transition of the global electricity system. In this study, we precisely examine whether and how renewable energy FDI affects global power sector green transition. In so doing, we use a unique firm project-level global dataset of renewable energy FDI over a long period of time that combines project-level data and national electricity generation data.

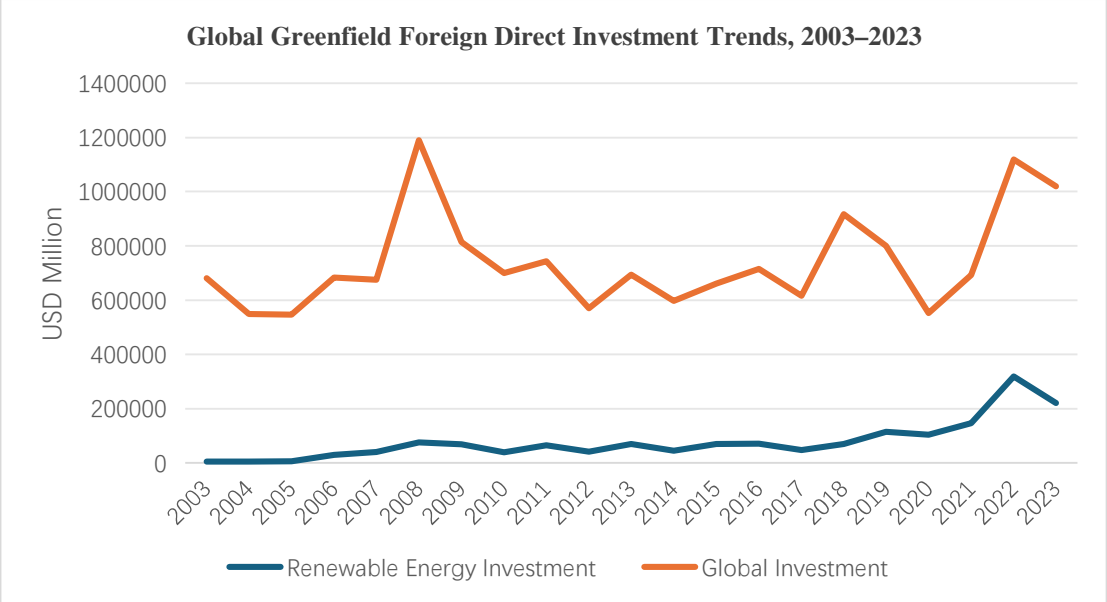


Fig. 1. Global Greenfield Investment Trends from 2003 to 2023.
Source: *fDi Markets* Database.

Increasing investment in renewable energy is essential for reducing CO_2 emissions. These investments bring various economic benefits, including access to advanced technologies, job creation, and improvements in labor productivity through training programs (Harrison and Rodríguez-Clare, 2010; Yan and Li, 2023; Abebe et al., 2022). FDI in the renewable energy sector has shown a significant upward trend in both developing and least developed countries (see Table 1). In 2023, the total renewable energy investment in developing economies reached USD 183.3 billion, representing a 4% increase from 2022, while the number of projects rose from 187 to 277, an increase of 48%. This indicates that developing countries have maintained steady growth in attracting renewable energy–related FDI, highlighting their

crucial role in the global energy transition. In contrast, the growth in least developed countries was even more pronounced: total investment surged from USD 4.8 billion to USD 41.6 billion, an increase of 763%, and the number of projects expanded from 13 to 24, up by 85%. Although the base remains relatively small, this suggests that least developed countries are emerging as new destinations for renewable energy FDI, with international capital increasingly flowing into these regions to support green infrastructure development and energy transition goals. Therefore, renewable energy investment has become an indispensable driver of the global shift toward a low-carbon energy system.

Table1

Sectors related to SDGs: announced greenfield projects in developing economies.

Economic grouping	**Developing economies**			**Least developed countries**		
	2022 (Million $)	2023 (Million $)	Growth%	2022 (Million $)	2023 (Million $)	Growth%
Total						
Value	261481	297746	14	9437	49157	421
Number of projects	1566	1866	19	66	91	38
Power						
Value	4080	7155	75	1865	671	-64
Number of projects	17	29	71	3	1	-67
Renewable energy						
Value	176342	183327	4	4824	41614	763
Number of projects	187	277	48	13	24	85
Greenfield projects	622000	749000	20	/	/	/

Source: World Investment Report, 2024.

According to the World Investment Report 2024 (UNCTAD, 2024), the value of cross-border greenfield project announcements in industries related to the Sustainable Development Goals (SDGs) increased by 14% in 2023, while the number of projects rose by an even larger margin of 19%. However, this growth was mainly driven by a few key sectors—transport services accounted for roughly half of the total increase in both project number and value, while renewable energy contributed about one-quarter. Notably, although cross-border mergers and acquisitions have been declining, greenfield investment has continued to expand, particularly in the renewable energy sector. Figure 2 further illustrates the changes in the number of greenfield investment projects and the share of developing economies between 2011 and 2023. Overall, different economies have similar trends. From 2011 to 2019, global greenfield investment remained relatively stable, but it rebounded significantly after 2020. The share of developing economies in global greenfield projects increased from 33% in 2020 to 43% in 2023. This recovery is closely linked to the rapid growth of FDI in the renewable energy sector in recent years, particularly in clean energy projects such as solar, wind, and hydropower. Developing countries have attracted a growing share of global renewable energy FDI, underscoring their rising importance in driving the global energy transition.

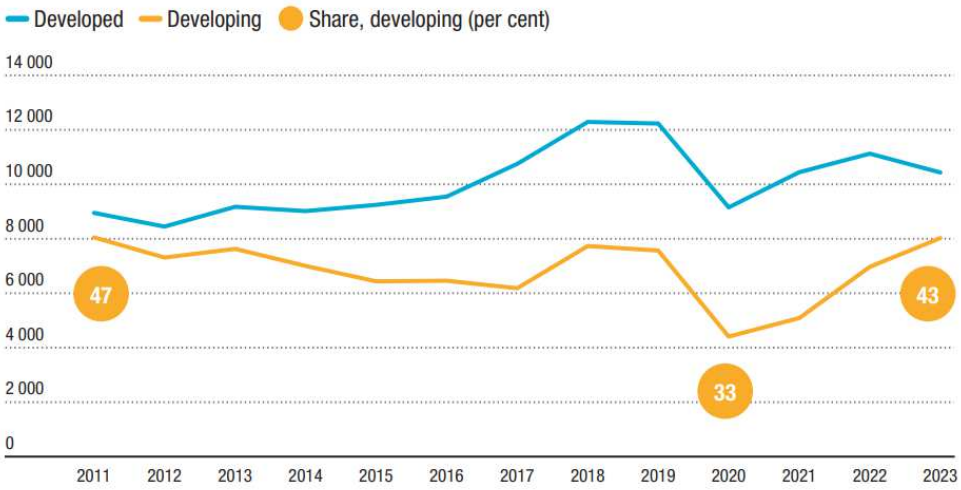


Fig. 2. Number of projects and share of greenfield projects in developed and developing countries. Source: World Investment Report, 2024.

This study defines "renewable energy FDI" as all investments made by multinational enterprises to advance generation technologies, upgrade power infrastructure, and drive the structural transition of the host country's electricity sector. The potential contribution of this study is the innovation of its research object. Existing research mostly generalizes overall FDI to investigate its impact on energy consumption (Shinwari et al., 2024), energy demand (Adom et al., 2019), and energy security (Fang et al., 2025), but lacks specialized definition and detailed analysis of "renewable energy FDI". We first construct a unique firm project-level global dataset of renewable energy FDI over a long period of time that combines project-level data and national electricity generation data. The specific procedures are as follows. First, we extract all energy-related projects from the *fDi Markets* database based on its “Sector” and “Cluster” classifications. Second, using a “green investment for electricity generation only” identification strategy, we manually code and classify each project by reviewing its source information to accurately identify renewable energy FDI and analyze its specific effects. Third, the renewable energy FDI dataset is then matched with national electricity generation data from the EIA by country and year, and organized into a balanced panel dataset. Furthermore, considering the potential endogeneity that countries with higher levels of green transition may be more likely to attract renewable energy FDI, we employ the system generalized method of moments (System GMM) estimator and instrumental variable (IV) regression to mitigate endogeneity concerns. Finally, we examine the heterogeneity effects of renewable energy FDI by distinguishing among different types of renewable energy sources, countries at different income levels, and various project types, focusing on their differential impacts on electricity generation, energy mix, and job creation.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and theoretical framework on the topic. Section 3 discusses methodology and data. Section 4 presents and discusses empirical results. Section 5 concludes the paper.

2. Literature Review and Theoretical Framework

2.1. Literature Review

Given its central role in both energy consumption and carbon emissions, the electricity sector is widely recognized as a critical lever for achieving carbon peaking and carbon neutrality targets. Existing

literature, both domestic and international, has largely concentrated on three core dimensions: FDI, energy structure transition, and the low-carbon development of the electricity sector.

2.1.1. The FDI-energy Nexus

The primary linkage between FDI and energy lies in energy consumption. Yahya and Rafiq (2020) finding that both greenfield and brownfield investments generally promote renewable energy consumption. Doytch and Narayan (2016) found that FDI has a significant inhibitory effect on non-renewable energy consumption, while it exerts a promoting effect on renewable energy consumption. For instance, Salim et al. (2017) employed an ARDL (Autoregressive Distributed Lag) model to examine the impact of FDI on energy consumption in China. Amoako and Insaidoo (2021) examined the relationship between FDI and energy consumption in Ghana. More recently, Shinwari et al. (2024) focused on economies along the Belt and Road Initiative (BRI), finding that while FDI affects energy consumption through green technology channels, it overall contributes to increased energy demand.

FDI can also affect energy consumption and efficiency to varying degrees across regions and sectors. Using the Blundell-Bond dynamic panel estimation technique, Doytch and Narayan (2016) examined data from 74 countries over the period 1985–2012. They found that sectoral FDI influx (manufacturing, services, mining, and financial services) reduces non-renewable energy and augments renewable energy consumption sources. However, the extent and significance of these impacts differ depending on the sectoral composition of FDI. Adom et al. (2019) reported a non-linear relationship between FDI and energy demand in Africa, suggesting the energy-saving benefits of FDI can only be realized when a country possesses sufficient technological absorptive capacity. In China, Wei et al. (2020) explored how FDI improves energy efficiency through mechanisms such as technology transfer and management upgrading under diversified openness channels. In the long run, Salim et al. (2017) noted a significant negative relationship between FDI and energy consumption, indicating that FDI may help curb energy demand growth or enhance energy efficiency.

2.1.2. FDI and Green Development

The pollution haven hypothesis (Sapkota and Bastola, 2017) and the halo effect hypothesis (Hille et al., 2019) provide important theories to explain the environmental effects of FDI. Empirical evidence supports both hypotheses: Yahya and Rafiq (2020) demonstrated that both greenfield FDI and brownfield FDI enhance renewable energy consumption. In countries with weak governance and high-risk environments, brownfield investment can directly promote energy structure transformation, while greenfield investment requires effective government performance to be effective. Tian et al. (2023) finding that joint growth of inward and outward FDI significantly reduces industrial pollution—an effect amplified by higher positioning in the global value chain. These contrasting perspectives highlight the complex dynamics within the FDI–green–energy nexus.

The global energy structure is undergoing a major transition from fossil fuel dominance to renewable energy. Within this process, green technology innovation (GTI) serves as a core driver for reconciling economic growth with environmental objectives (Hossain et al., 2024). Shinwari et al. (2024) emphasize the significance of FDI policies and green technologies in promoting energy demand in the BRI economies. He et al. (2025) developed an evolutionary game model of heterogeneous firms under IP protection to unravel the co-evolution of green innovation and energy transition. GTI can be assessed along three dimensions: quantity, quality, and sustainability. This multidimensional perspective captures the breadth, effectiveness, and long-term commitment of GTI, providing a more systematic basis for

understanding its role in advancing sustainable development (Wang et al., 2025).

2.1.3. FDI and Electricity Transition

FDI can promote the expansion and upgrading of electricity infrastructure in the host country, thereby accelerating electricity transition and increasing electricity supply. D'Amelio et al. (2016) revealed that multinational enterprises have significantly promoted electricity accessibility in Sub-Saharan Africa, serving as an important external force for energy popularization and infrastructure improvement. Using panel data from 36 Sub-Saharan African countries and applying the IV GMM method, Aluko et al. (2023) found that FDI itself has a significant positive effect on improving electricity coverage, and good governance can significantly enhance this positive impact of FDI.

Although existing literature has established a relatively rich theoretical and empirical foundation in the fields of energy consumption, energy demand, and FDI, several important gaps remain unaddressed. First, the classification of green FDI remains ambiguous. Many studies treat FDI as a homogeneous variable, lacking a clear definition and in-depth analysis of "renewable energy FDI" which limits the accurate identification of specific investment behaviors. Second, in the field of energy economics, current research generally overlooks the close connection between renewable energy FDI and the green transformation of the electricity sector, a key low-carbon industry. To contribute to this debate, this study focuses specifically on renewable energy FDI rather than total FDI. Using panel data from 185 sovereign countries over the period 2003–2023, the study systematically examines the role of renewable energy FDI in promoting the global green transition of the electricity sector. Furthermore, we explore the heterogeneous effects of renewable energy FDI from three dimensions: different energy type, income level and the project type (including new, expansion, and co-location). To mitigate endogeneity concerns, this study employed the system GMM estimator and the instrumental variables approach.

2.2. Theoretical Framework

This study develops a conceptual framework to clarify how renewable energy FDI affects the green transition of the global power sector. As shown in Fig. 3, the framework links renewable energy FDI to power sector transformation through two dimensions: direct effects and heterogeneous effects. These pathways jointly form the basis for the research hypotheses proposed in this study.

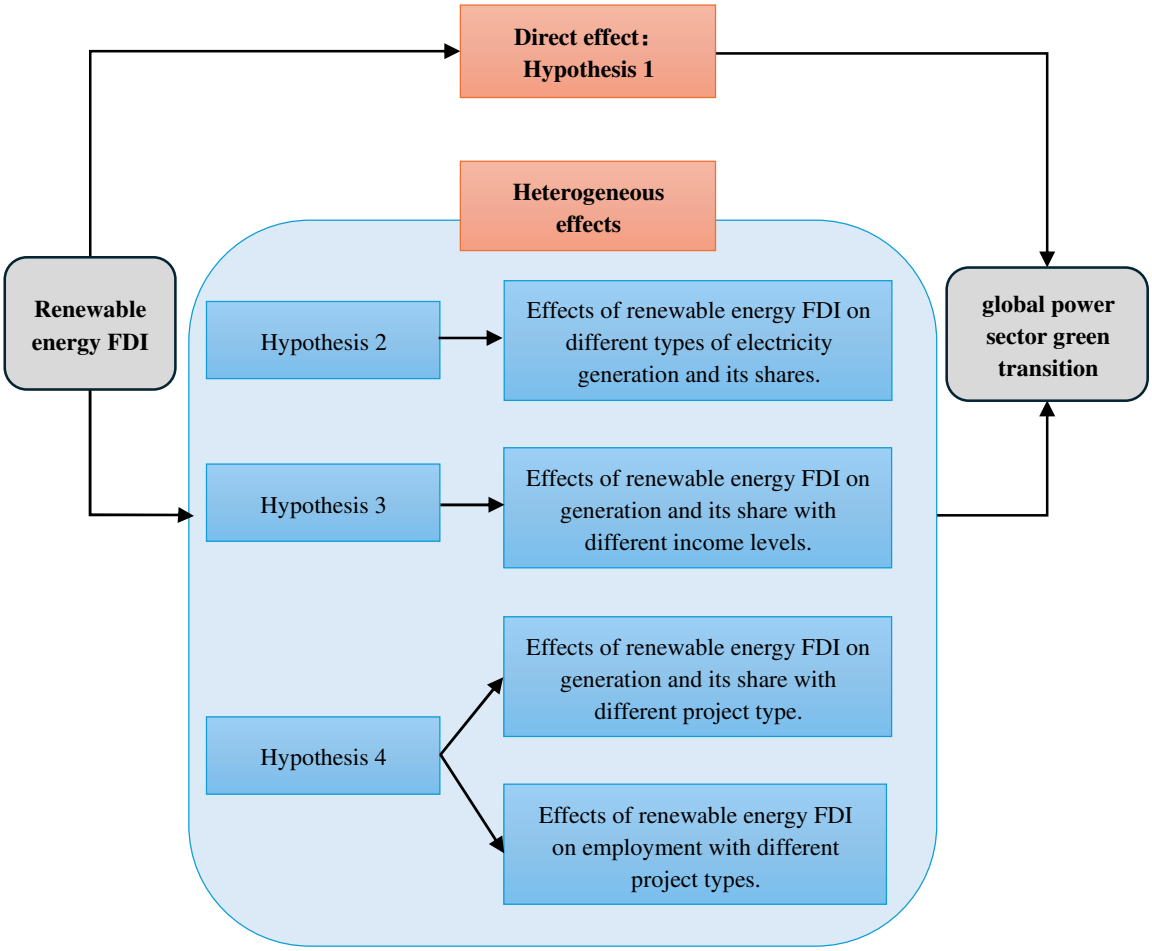


Fig. 3. Research hypothesis framework.

2.2.1. Direct Effects of Renewable Energy Investment in the Power Sector

A successful renewable energy transition should prioritize local manufacturing, skills development, energy funding and energy policy (Sen et al., 2025). Within the framework of endogenous growth theory, multinational enterprises (MNEs) transfer advanced technologies and additional capital to host countries through FDI, thereby stimulating economic growth. Therefore, FDI enhances production efficiency by transferring valuable capital and technology, while the efficient mobility of production factors further improves total factor productivity (TFP) in developing countries. In the context of green development, the localized green R&D activities of MNEs in host countries facilitate the introduction of new clean electricity generation technologies and the improvement of existing ones. Such activities accelerate the construction and deployment of renewable energy projects—such as solar, wind, hydro, and biomass power—thereby promoting the transition of the electricity sector from fossil-based to low-carbon energy sources. Under such circumstances, FDI is regarded as an important driver of electricity access (Dogan et al., 2024). Both developed and developing countries benefit from this process. Developed countries gain through profit repatriation and continuous innovation in green electricity technologies, while the effects are even more pronounced in developing countries. By leveraging foreign investment to build green infrastructure and expand electricity access, these countries promote socioeconomic development (Kanagawa & Nakata, 2008) and enhance labor productivity (Alam et al., 2018). Moreover, the green transition process typically requires coordinated participation of multiple stakeholders. Evidence from

evolutionary game research also shows that government–firm–society interaction can generate a "social win-win" effect that facilitates the adoption of green projects (Li et al., 2023).

Infrastructure development plays a critical role in ensuring adequate electricity supply. Given the strategic importance of electricity to business activities, MNEs often engage in the development of electricity infrastructure to meet increasing demand (D'Amelio et al., 2016). Chen and Lin (2021) find that the expansion of infrastructure will not only improve the energy services through direct effects but also through the indirect effects of promoting economic growth. In fact, a substantial body of literature has explored the relationship between FDI and factors such as economic growth, poverty reduction, financial development, environmental regulation, and energy consumption. In recent years, many scholars have become increasingly interested in the potential impacts of renewable energy FDI on host countries. However, this relationship remains insufficiently explored, primarily due to the absence of a comprehensive theoretical framework linking renewable energy FDI to the global power sector green transition. To address this gap, the present study constructs a dataset of renewable energy FDI projects to investigate their specific effects on the electricity sector and examines how three types of investment behaviors — new, expansion, and co-location — contribute to the process of electricity sector transformation.

Currently, the environmental impact of FDI is primarily explained by two competing hypotheses: the Pollution Halo Hypothesis and the Pollution Haven Hypothesis (Eskeland and Harrison, 2003; Duan and Jiang, 2021). The Pollution Halo Hypothesis suggests that FDI can improve the environmental quality of host countries through technology spillovers, managerial expertise, and the transmission of environmental standards. In contrast, the Pollution Haven Hypothesis posits that multinational enterprises from developed economies tend to relocate pollution-intensive and energy-consuming industries to developing countries with lax environmental regulations to avoid high compliance costs. Together, these two hypotheses capture the essential relationship between foreign capital inflows and environmental outcomes. Empirical evidence remains mixed. Keller and Levinson (2002) found that reductions in production costs were associated with a decline in FDI in heavy manufacturing industries, particularly in the chemical sector, while Wagner and Timmins (2009) confirmed the presence of the pollution haven effect in the chemical industries of 163 countries. However, many of these studies are based on aggregate FDI data and overlook the heterogeneity of investment motives and sector-specific transmission mechanisms. This study examines the environmental effects of renewable energy FDI across countries with different income levels. Since renewable energy FDI introduces advanced technologies, capital inflows, and management practices, while also fostering the development of related upstream and downstream industries—such as the manufacturing of turbines, hydropower equipment, and solar panels—it is reasonable to assume that renewable energy FDI aligns more closely with the Pollution Halo Hypothesis. Taking this into account, we propose Hypothesis 1.

Hypothesis 1: Renewable energy FDI promotes the global power sector green transition.

2.2.2. Heterogeneous Effects of Renewable Energy Investment in the Power Sector

Building on the analysis of direct effects, the heterogeneous impacts of renewable energy FDI on the electricity sector can be summarized in three main dimensions.

(1) Different types of renewable energy exhibit substantial differences in resource endowments, technological maturity, investment intensity, and grid integration constraints, leading to heterogeneous marginal effects of renewable energy investment across generation technologies. Solar and wind projects are characterized by relatively high technological maturity, strong modularity, and shorter construction

cycles. Once foreign capital enters, these projects can rapidly expand installed capacity and improve generation efficiency through capital inflows, the introduction of advanced equipment, and the spillover of managerial expertise (UNCTAD, 2024). Moreover, MNEs possess clear ownership advantages in photovoltaic module production, wind turbine manufacturing, and system integration, which helps lower technological barriers and alleviate financing constraints in host countries, thereby accelerating the pace and magnitude of renewable energy structure optimization. In contrast, biomass projects rely heavily on feedstock supply systems, regional agricultural structures, and logistics networks, and their technological pathways and business models tend to be more localized. Although foreign investment can facilitate project implementation to some extent, its marginal output effects are relatively limited. As a result, the promoting effect of renewable energy FDI on biomass power generation is likely to be weaker than that on solar and wind power. Taking this into account, we propose Hypothesis 2.

Hypothesis 2: Renewable energy FDI exhibits significant heterogeneity in its effects on different types of electricity generation and its shares, with stronger impacts on solar and wind power.

(2) To balance economic development and sustainability, Ruan et al. (2025) advise improving renewable energy investments, applying strict carbon pricing policies, and supporting technical innovation. High-income countries possess greater financial resources to support technological innovation, and green technologies represent a key means of reducing energy consumption, promoting power structure transformation, and achieving sustainable development. As such, green technological progress constitutes one of the most important channels through which renewable energy FDI exerts its effects. Advances in green technology increase the substitutability of production factors, thereby raising the marginal rate of substitution of traditional energy and facilitating the replacement of conventional energy with cleaner alternatives (Gerstlberger et al., 2014). However, for middle-income and low-income countries that face constraints in mobilizing fiscal resources, limitations in grid infrastructure, policy continuity, and institutional quality persist. In these contexts, foreign investment projects may remain largely at the level of capital inflows, making it difficult for them to fully generate technological spillovers and structural upgrading effects, which in turn weakens the actual transition impact of renewable energy FDI. Taking this into account, we propose Hypothesis 3.

Hypothesis 3: Renewable energy FDI has a more pronounced promoting effect in high-income countries, while its impact is relatively weaker in low-income and middle-income countries.

(3) After MNEs complete their initial renewable energy investments, subsequent investment decisions—such as expansion or co-location project—are jointly influenced by prior investment experience, host-country market potential, and policy environment stability. On the one hand, home countries can alleviate domestic resource constraints on economic growth and technological progress through outward investment, generating cumulative investment effects and further attracting high-skilled labor to engage in innovation activities, thereby fostering dynamic technological upgrading. On the other hand, host countries benefit from capital inflows and advanced managerial expertise, which strengthen learning and competition effects among local firms, reduce the risk of market monopolization, and improve overall industry efficiency. As capital continues to accumulate, the density of projects increases, gradually giving rise to regional energy industry clusters. This process not only significantly expands employment but also promotes the green upgrading of the power sector by optimizing the electricity supply structure and reducing carbon emissions, ultimately contributing to sustainable economic development in developing countries. Large-scale photovoltaic investments in Pakistan have been shown to play a positive role in advancing the host country's energy transition (Aqeeq et al., 2023). However, these effects depend on project types. New projects typically involve multiple stages, including site

approval, infrastructure construction, and grid connection upgrades, which entail high upfront fixed costs and long construction periods. As a result, their investment effects are difficult to fully translate into electricity output and employment growth in the short term, although they exhibit strong long-term potential once projects become operational. In contrast, expansion projects and co-location projects rely on existing power facilities, mature technological pathways, and stable market networks, enabling capacity expansion and factor allocation at lower marginal costs. Consequently, their investment effects are more likely to be reflected in short-term increases in electricity generation, improvements in the power mix, and job creation. Taking this into account, we propose Hypothesis 4.

Hypothesis 4: Among different project types, expansion projects and co-location projects exert significantly stronger promoting effects on power sector green transition and job creation than new projects.

3. Empirical Strategy and Data

3.1. Empirical Methodology

This study examines the impact of renewable energy FDI on the green transformation of the global electricity industry, utilizing both static and dynamic models. The static fixed effects model cannot adequately address the potential endogeneity concerns in this study. Countries with better green power transition may attract more FDI, rather than FDI causing the transition. The dynamic GMM estimation method is well-suited to mitigate endogeneity and other econometric challenges commonly encountered in empirical economic research. To further ensure the robustness of the results, an instrumental variables approach is subsequently employed for validation.

3.1.1. Static Model

The static panel model is constructed in Eq.(1) using the findings from prior research conducted by Razzaq et al. (2023). Renewable energy projects such as wind farms and photovoltaic power plants typically involve long construction and commissioning periods, resulting in a time lag between capital investment and its realization in electricity generation and power structure adjustment. To account for this lag effect, this study uses a one-period lag of renewable energy FDI as the core explanatory variable. Consequently, it aligns investment timing with observed electricity outcomes and captures the delayed impact of renewable energy FDI on the green transition of the power sector.

$$Ren_share_{it} = \alpha_0 + \alpha_1 Cit_{i,t-1} + \alpha_2 Control_{it} + \gamma_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Ren_share_{it} refers to the dependent variable of country *i*'s renewable energy generation(% of total generation) in year *t*; $Cit_{i,t-1}$ presents the core independent variables of renewable energy FDI; $Control_{it}$ refers to six control variables; ε_{it} is the perturbation term; α_0 presents the constant term; α_1 and α_2 are the estimated coefficients. To control for unobserved heterogeneity across countries and over time, this study adopts a two-way fixed effects model that includes both country (γ_i) and year (λ_t) fixed effects.

3.1.2. Dynamic Model

The dynamic panel model of the System generalized method of moments (GMM) is also utilized to mitigate potential endogeneity issues that can arise with static models. First, Considering the difficulty in finding external instruments and justifying their validity, this study relies on the use of the lags of the variables considered as endogenous as instruments in the GMM estimation. This approach offers robust performance in addressing issues of endogeneity and autocorrelation in models (Arellano and Bover, 1995; Blundell and Bond, 1998).

$$Ren_share_{it} = \alpha_0 + \beta_1 Ren_share_{i,t-1} + \alpha_1 Cit_{it} + \alpha_2 Control_{it} + \gamma_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$Ren_share_{i,t-1}$ indicates the lagged dependent variable of Ren_share_{it}. The Hansen J-statistics is used to test the reliability of the GMM estimates. The estimates of the GMM are reliable when the Hansen J-statistics rejects the null hypothesis that the instruments are over-identified.

3.2. Variables

Core independent variables: renewable energy FDI, measured as the Total capital investment of all selected renewable projects. The capital investment is typically used as an indicator of project scale in FDI analysis. FDI projects are classified into three project types: new, expansion and co-location.

Dependent variable: (1) Share of renewable energy generation (*Ren_share*): renewable energy is a feasible alternative to fossil fuels. Compared with fossil fuels, renewable energy has the advantages of renewability and environmental friendliness, while fossil fuels are the main contributors to carbon emissions (Li et al., 2025). This study defines *Ren_share* as the proportion of renewable energy generation in total electricity generation, which can more intuitively reflect the energy structure and the degree of green transition in the electricity industry; (2) Renewable energy generation (*Ren*): To further analyze the relationship between the scale of renewable energy development and renewable energy FDI, this study also uses the absolute value of Ren as a dependent variable. This indicator can more directly reveal the impact of renewable energy FDI on the expansion of actual generation capacity and helps to understand its policy and economic implications from the perspective of scale; (3) Fossil fuel electricity generation and its share *(Fos*, *Fos_share*); (4) Wind power generation and its share (*Win, Win_share*); (5) Solar power generation and its share (*Sol & Sol_share*); (6) Hydropower generation and its share (*Hyd, Hyd_share*). These various types of electricity generation help identify the specific impacts of renewable energy FDI on different energy sources.

Control variable: Guided by existing studies (Garrone et al., 2019), this study includes the following control variables: (1) GDP (constant 2015 US$). GDP is used to capture the economic development, measured as the log of real GDP; (2) Total population. The Population growth of a country also impacts public investments in renewable energy, measured as the log of real population; (3) Trade (% of GDP). In general, a higher degree of economic openness enables a country to better facilitate the technological spillover effects of FDI. Trade is measured as total trade (exports plus imports) as percentage of GDP; (4) Urban population. It is used to indicate the level of urbanization, which may affect energy demand patterns and infrastructure development; (5) Inflation, consumer prices (annual %). Used to reflect macroeconomic stability. Its fluctuations may influence investment behavior and the risk assessment of renewable energy projects; (6) Inflation, GDP deflator (annual %). As a broad indicator of price level changes and the macroeconomic environment, it complements the CPI by capturing the potential impact of inflation on energy production and investment.

3.3. Data

This study uses project databases from the *fDi Markets* for the period 2003-2023, which is maintained by the *Financial Times* (UK), officially published by *fDi Intelligence*. This database is the most comprehensive source of project-level cross-border greenfield investments available, covering all countries and sectors worldwide since 2003. This unbalanced panel data contains a wide range of indicators, including the name of the firm engaging in FDI, the year of investment, the capital investment, the name of the destination country and source country, the recipient industry sector, the project type, the jobs created and the source URL. Numerous studies have employed this database to investigate

Greenfield FDI (Yahya and Rafiq, 2020). *fDi Markets* is the primary source of greenfield FDI data for various international organizations, consultancies, major corporations and over 100 governments (Desbordes and Wei, 2017). Moreover, the unbalanced nature of *fDi Markets* implies that the industry distribution of FDI projects may vary across countries, and the entry time of different countries into the sample is not fixed. In our study, the most critical step is how to extract global renewable energy FDI projects from the database. We follow a multi-step manual filtering and cleaning procedure, detailed as follows.

First, we filter projects from the *fDi Markets* database using various classification criteria. We exports all global project data from 2003 to 2023. Based on the "Cluster" classification, we select projects categorized under "Energy" and "Environmental Technology", resulting in 18,946 entries. Alternatively, filtering by the "Sector" classification yields 12,321 records. However, these preliminary results may include both renewable and non-renewable energy projects. To enhance the accuracy of the dataset, we further manually verify each project by reviewing the "Source URL" field, which provides links to the original source of information. By clicking and inspecting each source, we classify projects into three categories: renewable energy FDI (coded as 1), non-renewable energy FDI (coded as 0), and uncertain cases (coded as 2). A project is identified as renewable energy FDI if it involves the construction of new renewable power plants, manufacturing of renewable energy equipment (wind turbines or photovoltaic modules), or reinvestment at existing renewable energy sites. Projects with inaccessible links due to outdated URLs are marked as uncertain. All remaining projects are considered non-renewable energy FDI. Ultimately, 7,155 projects are confirmed as renewable energy FDI. Based on this refined dataset, this study constructs a panel dataset of global renewable energy FDI from 2003 to 2023. We aggregate the following key variables by country and year: (1) the Total capital investment of all selected renewable energy projects (core independent variable); (2) the number of renewable FDI projects; (3) the number of new jobs created; (4) the capital investment categorized by project type (new, expansion, and co-location).

Second, we match the renewable energy FDI dataset with global electricity generation data by country and year. The electricity generation data is sourced from the EIA, which provides comprehensive coverage across countries and regions. This dataset includes not only total electricity generation but also disaggregated generation by energy type (like fossil fuels and renewables), offering insight into each country's energy structure and its evolution over time. We collect national data on total electricity generation, fossil fuel generation and renewable energy generation, and calculate the share of each energy source in total electricity generation. The share of renewable energy generation serves as our core dependent variable.

Third, we clean the merged dataset as follows:(a) If renewable energy FDI data is missing, we treat it as zero, indicating no renewable energy FDI occurred that year; (b) If electricity generation data is missing, it is also set to zero, indicating no electricity generation activity that year; (c) We exclude countries with no recorded electricity generation throughout the entire study period, as they lack an active power sector and cannot be meaningfully evaluated for green transition; (d) We remove regional or organizational-level observations, retaining only country-level data to ensure consistency and comparability. After the above processing, the final dataset comprises 3,885 observations across 185 sovereign countries. Moreover, since *Ren_share* is lagged by one period and used as an instrumental variable in the GMM model, the empirical analysis covers the period from 2004 to 2023. Descriptive statistics of the variables are presented in Table 2.

3.4. Descriptive Statistics

Descriptive statistics provide a comprehensive overview of the data. As shown in Table 2, the average total capital investment in renewable energy FDI projects is about USD 0.447 billion. The standard deviation is as high as USD 2.463 billion. This suggests that renewable energy FDI is highly concentrated, with a few large projects raising the overall average. On average, each country-year observation includes 1.649 new projects, 0.128 expansion projects, and 0.056 co-location projects. Among them, new investments account for the largest share at approximately USD 0.420 billion, while expansion and co-location projects involve smaller investment amounts, around USD 0.017 billion and USD 0.011 billion respectively. This distribution aligns with the project count and further confirms that new projects dominate renewable energy FDI activity. Regarding employment contributions, each country generates an average of 160 new jobs per year, though with a very high standard deviation, reflecting substantial heterogeneity across projects. Most projects create relatively few jobs, whereas new employment is largely concentrated in large-scale projects, particularly in early years when investment levels were low. A few major projects can generate a considerable number of jobs, with a maximum of 24,775. This indicates that renewable energy FDI is highly concentrated not only in capital investment but also in its employment impact. The average total electricity generation is 123.497 billion kWh, with a standard deviation of 547.074 billion kWh, suggesting large cross-country disparities, with industrialized countries contributing most of the global capacity. Among fossil fuel generation, coal generation is the largest contributor (46.800 billion kWh), followed by natural gas generation (27.758 billion kWh) and oil generation (4.938 billion kWh). In terms of renewable energy, hydroelectricity is the primary source (19.880 billion kWh), followed by wind (4.619 billion kWh) and solar (2.070 billion kWh). On average, renewable energy accounts for 34.2% of total electricity generation (29.494 billion kWh), while fossil fuels account for 61.9% (80.519 billion kWh), indicating that fossil fuels remain the dominant source of electricity generation in most countries.

Table 2

Descriptive statistics of the variables.

Variables	Description	Mean	Sd	Min	Max	Unit
Job	new jobs created	160.046	809.661	0.000	24775.000	number of jobs
Newc	new projects	1.649	5.222	0.000	84.000	number of projects
Expc	expansion projects	0.128	0.853	0.000	29.000	number of projects
Locc	co-location projects	0.056	0.340	0.000	7.000	number of projects
Cin	New capital investment	0.420	2.364	0.000	90.844	billion USD
Cie	Expansion capital investment	0.017	0.190	0.000	8.697	billion USD
Cil	Co-location capital investment	0.011	0.112	0.000	3.617	billion USD
Cit	Total capital investment	0.447	2.463	0.000	90.844	billion USD
Gen	Total generation	123.497	547.074	0.000	9232.794	billion kWh
Fos	Fossil fuels generation	80.519	380.139	0.000	5928.029	billion kWh
Coa	Coal generation	46.800	316.931	0.000	5499.193	billion kWh
Nat	Natural gas generation	27.758	107.121	0.000	1806.063	billion kWh
Oil	Oil generation	4.938	15.987	0.000	225.478	billion kWh
Ren	Renewable energy generation	29.494	132.337	0.000	2885.394	billion kWh
Hyd	Hydroelectricity generation	19.880	84.638	0.000	1321.511	billion kWh
Geo	Geothermal generation	0.394	1.840	0.000	16.936	billion kWh
Sol	Solar generation	2.070	17.281	0.000	584.150	billion kWh
Win	Wind generation	4.619	32.380	0.000	885.870	billion kWh
Bio	Biomass and waste generation	2.526	10.445	0.000	188.134	billion kWh

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Variables	Description	Mean	Sd	Min	Max	Unit
Fos_share	Share of fossil fuel generation	0.619	0.340	0.000	1.085	-
Coa_share	Share of coal generation	0.118	0.219	0.000	1.000	-
Nat_share	Share of natural gas generation	0.213	0.303	0.000	1.084	-
Oil_share	Share of oil generation	0.285	0.367	0.000	1.000	-
Ren_share	Share of renewable energy generation	0.342	0.334	0.000	2.085	-
Hyd_share	Share of hydroelectricity generation	0.275	0.317	0.000	1.000	-
Geo_share	Share of geothermal generation	0.009	0.042	0.000	0.485	-
Sol_share	Share of solar generation	0.013	0.032	0.000	0.401	-
Win_share	Share of wind generation	0.021	0.059	0.000	0.590	-
Bio_share	Share of biomass and waste generation	0.024	0.063	0.000	0.835	-
N			3700			

4. Estimation Results

4.1. Baseline Estimates

Table 3 reports the baseline results for Eq (1). Columns (1) and (3) use renewable energy generation (*Ren*) and its share as the dependent variables. Columns (2) and (4) further introduce all control variables to test the robustness of the results. In all models, the coefficient of the core independent variable *Cit* is positive and statistically significant at the 1% or 5% level. This indicates that foreign investment in the renewable energy sector and the expansion of power generation capacity can promote the green transition of the power structure. This finding is consistent with previous research by Kushawaha (2025), which suggests a U-shaped relationship between greenfield FDI and renewable energy capacity, and a positive effect of M&A FDI on renewable energy capacity. Specifically, an additional USD 1 billion in renewable energy FDI is associated with an average increase of approximately 2.034 billion kWh in renewable energy generation, and an increase of about 0.002 percentage points in its share in total generation. These effects remain robust even after controlling for macroeconomic and structural factors.

After including control variables (Columns 2 and 4), the adjusted R^2 values increase, indicating improved explanatory power of the models. The results show that *ln*GDP is significantly positively associated with renewable energy generation (*Ren*), suggesting that higher levels of economic development are linked to greater use of renewable energy generation. However, GDP exhibits a significant negative effect on *Ren_share*, implying that in more developed economies, despite higher absolute renewable energy generation, its share may remain limited due to the dominant role of conventional energy sources. This outcome is consistent with that found in Sarkodie et al. (2020). Total population and trade openness generally show significant negative coefficients, suggesting that countries with larger populations and more open economies face greater pressure on energy supply or a stronger reliance on fossil fuels in their energy transition. Urbanization is significantly positively associated with *Ren*, reflecting how urban expansion may drive investment in energy infrastructure and renewable technologies. However, urbanization has a significantly negative effect on *Ren_share*, indicating that rapid urbanization may initially increase reliance on traditional energy sources. Lastly, the coefficients of the consumer price index and GDP deflator are statistically insignificant in most specifications, suggesting that these models do not provide evidence of a systematic association between short-term price fluctuations and the renewable energy outcomes examined.

Table 3

Baseline results: Effects of FDI on renewable energy generation and share.

Variables	(1)	(2)	(3)	(4)
	Dependent Variables			
	Ren	*Ren*	*Ren_share*	*Ren_share*
Cit	2.034***	2.102***	0.002***	0.002**
	(0.489)	(0.516)	(0.001)	(0.001)
*ln*GDP		90.716***		-0.061***
		(10.423)		(0.015)
*ln*POP		-192.297***		-0.124***
		(17.360)		(0.025)
Trade		-21.033**		0.140***
		(8.809)		(0.013)
Urban		909.595***		-0.308***
		(73.763)		(0.107)
Consumer		11.351		0.013
		(15.985)		(0.023)
Deflator		-0.110		-0.006
		(15.114)		(0.022)
N	3700.000	3061.000	3700.000	3061.000
R^2	0.030	0.129	0.086	0.181

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.2. Panel Unit Root Test

The HT test was used to conduct the unit root test for short panel data. This test is designed to analyze first-order autoregressive panel data models with serially uncorrelated errors, where N approaches infinity ($N \to \infty$) while T remains constant (Harris and Tzavalis, 1999). Table 4 conducts the HT test on all variables except the share of generation, primarily because ratio-type variables typically range between 0 and 1, are generally considered stationary by nature. The results show that, except for solar and wind generation, all other variables pass the HT test, indicating a good degree of stationarity. While some variables (such as *Job* and *Expc*) do not initially meet the criteria, they become stationary after first-differencing. Due to an insufficient number of non-zero observations, solar and wind generation could not be subjected to the unit root test; however, this does not affect the subsequent empirical analysis.

Table 4

The results of unit root test.

Variables	**HT test**	**Stationarity**	
	P-value	No difference	First-order difference
Job	1	Failed	Pass
Newc	0	Pass	
Expc	0.493	Failed	Pass
Locc	1	Failed	Pass
Cin	0	Pass	
Cie	1	Failed	Pass
Cil	1	Failed	Pass
Cit	0	Pass	
Gen	1	Failed	Pass
Fos	0.031	Pass	
Coa	0	Pass	

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Variables	HT test	Stationarity	
Nat	0.618	Failed	Pass
Oil	1	Failed	Pass
Ren	1	Failed	Pass
Hyd	0	Pass	
Geo	1	Failed	Pass
Sol	1	Failed	Failed
Win	1	Failed	Failed
Bio	1	Failed	Pass

4.3. Endogeneity Tests: System GMM and IV Results

Following the approach of Berk et al. (2020), this study employs the System GMM for dynamic panel data, combined with the instrumental variable approach, to mitigate potential endogeneity concerns. Table 5 presents three models: Models (1) and (2) are based on system GMM, with Model (2) including full control variables. Model (3) applies an instrumental variables (IV) approach using internet penetration and the rule of law index as instruments. Across all specifications, *Cit* remains positively and significantly associated with the *Ren_share*, confirming its role in promoting a greener electricity structure. The lagged dependent variable *L.Ren_share* is also significantly positive, suggesting a strong path dependency in green electricity transition—earlier progress tends to persist over time. From a robustness perspective, the AR (1) test shows significant first-order autocorrelation, while the AR (2) test is insignificant, indicating the absence of second-order autocorrelation. The Hansen test fails to reject the null hypothesis, supporting the validity of the instruments in the GMM estimation. Internet penetration measures the extent of digital and communications infrastructure development across countries, as captured by the share of individuals using the internet. This study uses internet penetration and the rule of law index as instrumental variables (Deng et al., 2024), based on two main reasons: (1) Well-developed internet infrastructure and a sound legal environment help attract green FDI; (2) Internet and the rule of law index are not directly related to the share of renewable energy generation. The instrumental variable regression results further confirm the positive impact of renewable energy FDI on the transformation of the electricity structure toward renewables. The Hansen test results indicate that the instruments are valid, and the model passes both the Kleibergen-Paap LM test and the Stock-Yogo weak instrument critical value test, suggesting that the instruments are strong and the model is well-identified. It supports the overall robustness of the model.

Table 5

Results of endogeneity problem.

	(1)	(2)	
	System GMM		Instrumental variable approach
Variables	Dependent Variables		
	Ren_share	*Ren_share*	*Ren_share*
L.Ren_share	0.982***	0.936***	
	(0.014)	(0.051)	
Cit	0.005**	0.004**	0.156***
	(0.002)	(0.002)	(0.035)
Control variables	No	Yes	Yes
N	3700	3416	2997
AR(1)	0.000	0.000	

AR(2)	0.108	0.111	
Hansen test	0.195	0.259	0.153

Notes：Robust standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.4. Robustness tests

In this section, robustness of our findings is assessed through several approaches. Specifically, we conduct robustness checks by employing lagged variables, adjusting the sample scope, and replacing the dependent variable.

4.4.1. Lagged Variable Test

First, to account for the potential lagged effects of renewable energy FDI (*Cit*) on the electricity structure, this study re-estimates the model by introducing one-year, two-year, and three-year lags of the core explanatory variable (see Table 6). The estimation results indicate that the coefficient of renewable energy FDI remains significantly positive across all lag specifications, with the significance level essentially unchanged. This suggests that the positive effect of renewable energy FDI on expanding renewable electricity generation and increasing its share in the electricity mix is not confined to the contemporaneous period but persists over a longer horizon. Furthermore, in the two-year and three-year lag specifications, the signs of the coefficients are consistent with those of the baseline estimates, and the magnitude changes are minimal. These results provide further evidence supporting the robustness of the baseline findings and demonstrate the sustained nature of the positive impact of renewable energy FDI.

Table 6

Robustness test: using lagged independent variable.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Dependent Variables					
	Ren	*Ren*	*Ren*	*Ren_share*	*Ren_share*	*Ren_share*
L.Cit	2.078***			0.002**		
	(0.551)			(0.001)		
L2.Cit		7.189***			0.004***	
		(1.107)			(0.002)	
L3.Cit			7.827***			0.004**
			(1.201)			(0.002)
*ln*GDP	90.427***	92.554***	90.522***	-0.061***	-0.056***	-0.049***
	(10.426)	(10.843)	(11.317)	(0.015)	(0.016)	(0.017)
*ln*POP	-192.621***	-199.366***	-206.866***	-0.124***	-0.126***	-0.131***
	(17.366)	(18.409)	(19.690)	(0.025)	(0.027)	(0.029)
Trade	-21.373**	-22.146**	-22.263**	0.140***	0.137***	0.134***
	(8.812)	(9.024)	(9.312)	(0.013)	(0.013)	(0.014)
Urban	912.918***	965.889***	1033.495***	-0.306***	-0.286**	-0.288**
	(73.834)	(78.605)	(84.654)	(0.107)	(0.115)	(0.125)
Consumer	10.988	8.463	6.160	0.013	0.014	0.011
	(15.991)	(15.959)	(15.880)	(0.023)	(0.023)	(0.023)
Deflator	-0.908	1.383	3.633	-0.007	-0.008	-0.007
	(15.119)	(15.156)	(15.148)	(0.022)	(0.022)	(0.022)
N	3061.000	2916.000	2769.000	3061.000	2916.000	2769.000
R^2	0.128	0.136	0.136	0.181	0.178	0.175

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.4.2. Sample Adjustment Test

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Second, to avoid potential bias arising from countries with no FDI inflows, the study adjusted the sample by excluding countries that did not receive any renewable energy FDI during the study period from 2003 to 2023. The model is then re-estimated using only countries with at least one recorded FDI inflow (see Table 7) . We adjust the sample, consider both *Ren* and *Ren_share* as dependent variables, and further disaggregate the analysis into three major renewable energy types: solar (*Sol, Sol_share*), wind (*Win, Win_share*), and biomass (*Bio, Bio_share*). The results show that, renewable energy FDI remains positively and significantly associated with overall renewable electricity generation and its share. Positive and statistically significant estimates are also found for the absolute generation of solar, wind, and biomass, and for the generation shares of solar and wind. The coefficient for the biomass share is positive but not statistically significant. This indicates that the main findings are not driven by no FDI countries and remain robust after their exclusion. Moreover, the marginal effects still vary across renewable energy types: solar and wind display larger positive coefficients, while biomass exhibits smaller but still statistically significant effects. These results further confirm the robustness and generalizability of renewable energy FDI's role in promoting diversified renewable energy development.

Table 7

Robustness test: with adjusted sample scope.

	(1) Renewable		(2) Solar		(3) Wind		(4) Biomass and waste	
Variables	Dependent Variables							
	Ren_share	*Ren*	*Sol_share*	*Sol*	*Win_share*	*Win*	*Bio_share*	*Bio*
Cit	0.002**	2.343***	0.001***	0.693***	0.001***	1.233***	0.000	0.189***
	(0.001)	(0.564)	(0.000)	(0.130)	(0.000)	(0.209)	(0.000)	(0.047)
*ln*GDP	-0.085***	118.648***	-0.027***	16.591***	-0.024***	27.948***	-0.020***	6.955***
	(0.017)	(12.741)	(0.004)	(2.932)	(0.007)	(4.726)	(0.006)	(1.065)
*ln*POP	-0.121***	-231.165***	0.007	-42.960***	-0.067***	-69.991***	-0.006	-20.531***
	(0.027)	(19.949)	(0.006)	(4.590)	(0.010)	(7.399)	(0.009)	(1.668)
Trade	0.147***	-17.426*	0.025***	-3.729	0.067***	-5.573	0.047***	-1.230
	(0.014)	(10.164)	(0.003)	(2.339)	(0.005)	(3.770)	(0.005)	(0.850)
Urban	-0.308***	1040.678***	0.135***	167.196***	-0.097**	286.491***	-0.100***	82.964***
	(0.111)	(81.594)	(0.025)	(18.776)	(0.043)	(30.265)	(0.037)	(6.823)
Consumer	-0.027	9.687	-0.001	0.470	-0.009	2.010	-0.002	0.633
	(0.030)	(22.108)	(0.007)	(5.087)	(0.012)	(8.200)	(0.010)	(1.849)
Deflator	0.012	-0.150	-0.003	0.040	0.002	0.362	-0.001	0.038
	(0.026)	(19.194)	(0.006)	(4.417)	(0.010)	(7.119)	(0.009)	(1.605)
N	2678	2678	2678	2678	2678	2678	2678	2678
R^2	0.204	0.149	0.363	0.113	0.326	0.112	0.153	0.151

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.4.3. Alternative Dependent Variable Test

According to the International Energy Agency (IEA) classification, power generation sources can be divided into two categories: renewable energy and fossil fuels. To examine the impact of renewable energy FDI on the energy structure from a reverse perspective, this study replaces the core dependent variable *Ren_share* with fossil fuel-based electricity generation and its share, further disaggregated into three types: coal, oil, and natural gas (see Table 8). The results show that renewable energy FDI is significantly negatively correlated with both fossil fuel generation and its share, with the strongest inhibitory effect on coal-fired power, followed by oil and natural gas. This suggests that an increase in renewable energy FDI helps host countries reduce their dependence on fossil fuels, particularly high-

carbon coal-fired power generation, and plays an important role in advancing the decarbonization of the electricity sector and replacing fossil fuel-based generation. Interestingly, while the share of natural gas in power generation shows a negative relationship, its absolute generation volume is positively associated with renewable energy FDI. This may be explained by the role of natural gas as a "transition fuel" in the shift from high-carbon to low-carbon energy systems, as it emits less CO_2 than coal and oil. Consequently, many countries, while expanding renewable energy capacity, also increase natural gas use to replace coal as a means of balancing electricity supply. Moreover, foreign investment in the renewable energy sector may be accompanied by parallel investments in natural gas projects, such as joint peak-load regulation and flexible generation. It highlights that the green transition is a gradual substitution process rather than an immediate phase-out of fossil fuels. Therefore, renewable energy FDI reduces the share of fossil fuels and increases the share of renewable energy, promoting the green transformation of the global electricity sector.

Table 8

Robustness test: using alternative dependent variables.

	(1) Fossil fuels		(2) Coal		(3) Oil		(4) Natural gas	
Variables	Dependent Variables							
	Fos_share	*Fos*	*Coa_share*	*Coa*	*Oil_share*	*Oil*	*Nat_share*	*Nat*
Cit	-0.001*	-0.255	-0.002***	-1.840**	0.001	-0.217***	-0.000	1.759***
	(0.001)	(0.822)	(0.000)	(0.795)	(0.001)	(0.056)	(0.001)	(0.249)
*ln*GDP	0.032**	213.355***	0.070***	198.915***	-0.075***	3.196***	0.035***	4.751
	(0.014)	(15.777)	(0.009)	(15.254)	(0.014)	(1.067)	(0.013)	(4.775)
*ln*POP	0.092***	-255.678***	0.014	-245.972***	-0.048**	13.967***	0.129***	-14.143*
	(0.023)	(25.924)	(0.015)	(25.065)	(0.023)	(1.753)	(0.022)	(7.845)
Trade	-0.092***	-41.337***	-0.034***	-27.247**	-0.003	-0.261	-0.054***	-12.665***
	(0.012)	(13.510)	(0.008)	(13.062)	(0.012)	(0.913)	(0.011)	(4.089)
Urban	0.216**	1565.303***	0.337***	1508.956***	0.297***	-17.980**	-0.410***	20.198
	(0.096)	(109.251)	(0.063)	(105.630)	(0.099)	(7.386)	(0.092)	(33.063)
Consumer	-0.013	37.075	0.014	36.463	-0.017	1.609	-0.010	-2.144
	(0.022)	(25.475)	(0.015)	(24.630)	(0.023)	(1.722)	(0.021)	(7.710)
Deflator	0.005	-5.139	-0.008	-6.053	0.008	-1.677	0.005	2.715
	(0.021)	(24.136)	(0.014)	(23.336)	(0.022)	(1.632)	(0.020)	(7.304)
N	3206	3206	3206	3206	3206	3206	3206	3206
R^2	0.128	0.148	0.081	0.136	0.135	0.054	0.071	0.062

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.5. Heterogeneity Analysis

In this section, we discuss the heterogeneity in the impact of renewable energy FDI on the green transition of the global electricity sector from three perspectives: differences in energy types, differences in national income levels, and differences in project types with respect to both renewable energy FDI effects and employment effects.

4.5.1. Renewable Energy Type

Table 9 estimates the effects of renewable energy FDI from two perspectives—different generation and its share—to further examine its impact on different types of renewable energy, namely solar (*Sol, Sol_share*), wind (*Win, Win_share*), and biomass (*Bio, Bio_share*). The results show that renewable

energy FDI has a significantly positive effect on all three energy types, both in terms of absolute generation and share in the power mix. This indicates that renewable energy FDI plays an active role in promoting the diversification of renewable energy sources. Specifically, each additional USD 1 billion in renewable energy FDI is associated with an average increase of approximately 697 million kWh in solar power generation and 1.232 billion kWh in wind power generation, as well as an increase of about 0.001 percentage points in their respective shares of the electricity structure. This suggests that renewable energy FDI has strongly supported the development of solar infrastructure—particularly in emerging economies where investment in solar technologies has grown rapidly in recent years. In countries rich in wind resources, foreign capital has also facilitated the construction of wind farms, the introduction of equipment, and the diffusion of wind power technologies. Although the marginal effect of FDI on biomass energy is comparatively smaller, it remains statistically significant. This confirms that renewable energy FDI has also played a positive role in driving biomass energy projects. Ramanauske et al. (2023) demonstrated, through case studies of European countries, the contribution of biomass energy utilization to economic structural transformation and the optimization of energy systems. In sum, renewable energy FDI contributes not only to the overall green transformation of the electricity sector but also to the technological development and synergy of renewable energy, with particularly strong marginal effects observed in the solar and wind sectors. This provides important guidance for policymakers when formulating investment-oriented policies in specific energy sub-sectors.

Table 9

Effects of renewable energy FDI on different types of generation and share.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Dependent Variables					
	Sol	*Sol_share*	*Win*	*Win_share*	*Bio*	*Bio_share*
Cit	0.697***	0.001***	1.232***	0.001***	0.187***	0.000
	(0.119)	(0.000)	(0.192)	(0.000)	(0.043)	(0.000)
*ln*GDP	13.038***	-0.014***	22.323***	-0.013**	5.585***	-0.012***
	(2.282)	(0.003)	(3.677)	(0.005)	(0.832)	(0.004)
*ln*POP	-35.130***	-0.002	-57.911***	-0.078***	-17.230***	-0.016**
	(3.750)	(0.006)	(6.042)	(0.009)	(1.367)	(0.007)
Trade	-3.460*	0.028***	-5.610*	0.059***	-1.267*	0.042***
	(1.954)	(0.003)	(3.149)	(0.005)	(0.713)	(0.004)
Urban	138.349***	0.082***	239.566***	-0.051	68.721***	-0.088***
	(15.805)	(0.024)	(25.465)	(0.037)	(5.762)	(0.031)
Consumer	0.992	0.006	2.514	-0.010	0.757	-0.005
	(3.685)	(0.005)	(5.938)	(0.009)	(1.344)	(0.007)
Deflator	-0.000	-0.006	0.420	0.002	0.037	-0.000
	(3.492)	(0.005)	(5.626)	(0.008)	(1.273)	(0.007)
N	3206.000	3206.000	3206.000	3206.000	3206.000	3206.000
R^2	0.101	0.345	0.101	0.300	0.135	0.140

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.5.2. Income Levels

To explore whether the effects of renewable energy FDI vary across countries with different income levels, we classify countries based on the World Bank. The World Bank 2023 fiscal year defines low-income economies as countries with a GNI per capita of US$1145, lower-middle-income as countries with a GNI per capita of between US$1146 and US$4515, upper-middle-income as countries with a GNI per capita of between US$4516 and US$14005, and high-income economies as countries with a GNI per

capita of more than US$14006 (World Bank, 2023). Table 10 reports the heterogeneous effects of renewable energy FDI on both renewable energy generation (*Ren*) and its share (*Ren_share*) across countries with different income levels. The four model groups correspond to low-income (L), lower-middle-income (LM), upper-middle-income (UM), and high-income (H) countries, as classified by the World Bank's 2023 standard. The estimations are conducted using a two-way fixed effects model.

The results reveal that renewable energy FDI has a significant positive effect in high-income countries, indicating that these economies are more capable of translating foreign investment into increased renewable energy generation and a greener energy mix. One possible interpretation is that stronger infrastructure, institutions, and technological absorptive capacity in high-income economies may facilitate the utilization of foreign renewable energy investment. In contrast, the effects of renewable energy FDI in low-income countries are insignificant, possibly reflecting weak institutional support and limited absorptive capacity for green investment. Moreover, the model fit for the high-income group (R^2 = 0.398) is considerably higher than that of other groups, implying that developed countries, through the introduction and diffusion of advanced technologies, have improved energy efficiency and enhanced renewable energy generation capacity. These findings further indicate that the explanatory power of renewable energy FDI for green transformation is stronger in high-income countries and provide empirical support for the technology effect proposed in the theoretical framework.

Table 10

Effects of renewable energy FDI on generation and its share with different income levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	L		LM		UM		H	
Variables	Dependent Variables							
	Ren	*Ren_share*	*Ren*	*Ren_share*	*Ren*	*Ren_share*	*Ren*	*Ren_share*
Cit	-0.060	-0.000	0.273	0.000	6.999	-0.005	3.972*	0.004***
	(0.242)	(0.003)	(0.229)	(0.000)	(5.006)	(0.004)	(2.047)	(0.001)
*ln*GDP	2.091	-0.019	38.071	-0.016	202.120	-0.021	2.488	-0.011
	(2.038)	(0.114)	(23.489)	(0.072)	(195.224)	(0.034)	(22.929)	(0.095)
*ln*POP	-1.158	-0.267	-52.130	-0.248	-276.504	0.088	-65.562**	-0.067
	(2.594)	(0.280)	(33.351)	(0.201)	(250.294)	(0.121)	(32.393)	(0.186)
Trade	-0.877	0.031	0.383	0.058	-1.349	0.003	-24.042	0.282
	(1.019)	(0.066)	(7.462)	(0.038)	(28.232)	(0.030)	(18.473)	(0.185)
Urban	3.301	-1.742*	127.660	0.423	1651.549	-0.075	48.596	0.839
	(8.247)	(0.886)	(94.798)	(0.476)	(1550.043)	(0.348)	(112.569)	(0.631)
Consumer	2.755***	0.107***	-1.451	-0.071**	11.585	-0.040	16.267	0.241
	(0.502)	(0.038)	(2.962)	(0.032)	(37.545)	(0.056)	(32.573)	(0.186)
Deflator	-0.100	-0.045	1.830	0.064*	-3.625	-0.024	-0.774	0.028
	(0.487)	(0.040)	(3.093)	(0.034)	(20.312)	(0.037)	(7.827)	(0.047)
N	528	528	822	822	746	746	919	919
R^2	0.159	0.101	0.148	0.100	0.173	0.128	0.272	0.398

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.5.3. Project Type

To further examine heterogeneity across project types, we divide renewable energy FDI into three categories based on *fDi Markets* indicators: new projects, expansion projects, and co-location projects. Using the amount of capital investment as the proxy, three types of investment variables are constructed, namely *Cin*, *Cie*, and *Cil*. This study estimates their respective effects on renewable energy generation and its share by using the two-way fixed effects model. Results are shown in Table 11. Capital investment

in new projects does not show statistically significant effects in the short term, possibly due to long construction lead times and high initial infrastructure costs. However, when incorporating a two-period lagged variable (*L2.Cin*), the effect becomes significantly positive, indicating that new projects begin to yield output after two years. This suggests that policy design for renewable energy FDI should take the project life cycle into account. In contrast, expansion and co-location projects show significant positive effects. Every additional USD 1 billion in FDI through expansion projects increases the renewable energy share by approximately 1.6%, and co-location projects raise it by about 2.4%. These projects benefit from existing infrastructure and site advantages, resulting in faster and more efficient capital conversion, especially in regions with stable policy and developed facilities. These findings are consistent with UNCTAD (2022). New projects in the renewable energy sector possess significant long-term strategic value, but their output tends to experience greater delays. Expansion and co-location projects exhibit stronger efficiency and more pronounced short-term impacts.

Table 11

Effects of renewable energy FDI on generation and its share with different project type.

	(1)		(2)		(3)		(4)	
	New		Expansion		Co-location		New	
Variables	Dependent Variables							
	Ren	*Ren_share*	*Ren*	*Ren_share*	*Ren*	*Ren_share*	*Ren*	*Ren_share*
Cin	1.954	0.002						
	(1.238)	(0.001)						
Cie			23.172**	0.016***				
			(9.995)	(0.004)				
Cil					33.185***	0.024**		
					(8.563)	(0.010)		
L2.Cin							6.800**	0.004*
							(2.932)	(0.002)
N	3061	3061	3061	3061	3061	3061	2769	2769
R^2	0.128	0.181	0.128	0.181	0.127	0.180	0.134	0.175

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.5.4. Employment Effects by Project Type

Foreign direct investment can significantly promote employment growth in the host country, including direct, indirect, and induced employment (Zhao et al., 2024). Building upon this, the present study further explores the employment effects of renewable energy FDI across different project types. As shown in Table 12, the empirical results indicate that renewable energy FDI has an overall significantly positive effect on job creation, with an additional USD 1 billion in renewable energy FDI is associated with approximately 243 new jobs. However, considerable heterogeneity exists among project types. Specifically, co-location projects exhibit the strongest marginal employment effects, creating around 2127 jobs per USD 1 billion—substantially higher than new and expansion projects. This may be attributed to the fact that co-location projects are typically implemented using existing infrastructure, labor, and technological capacity, thereby achieving higher capital conversion efficiency and greater employment absorption. This finding aligns with the results reported in Table 11. Co-location projects not only promote renewable energy generation but also significantly enhance employment outcomes. In contrast, new projects often require longer construction periods and are more reliant on automation, resulting in lower employment intensity per unit of investment. Policymakers may consider project-type heterogeneity when designing renewable energy investment policies, while balancing short-

run employment outcomes against longer-term generation, cost, and infrastructure objectives. Therefore, renewable energy projects significantly increase power generation and employment, and subsequent investment decisions are jointly shaped by market size and policy conditions.

Table 12

Effects of renewable energy FDI on employment with different project types.

	(1)	(2)	(3)	(4)
Variables	Dependent Variables			
	Job	*Job*	*Job*	*Job*
Cit	243.490***			
	(28.073)			
Cin		245.074***		
		(28.298)		
Cie			902.423**	
			(400.525)	
Cil				2126.636***
				(253.493)
N	3206.000	3206.000	3206.000	3206.000
R^2	0.557	0.536	0.112	0.161

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

5. Conclusions and implications

Electricity is a marker for development (Dinkelman, 2011). Since 2010, global renewable electricity generation has shown a sustained upward trend, with its share rising markedly after 2015. This evolution aligns closely with the accelerated implementation of global low-carbon transition policies, including the signing of the *Paris Agreement*, the official launch of the United Nations Sustainable Development Goals, and the introduction of renewable energy development strategies and targets by many countries. These policy frameworks not only provide clear institutional guidance but also significantly enhance national incentives for renewable energy investment and deployment. Unlike previous studies that primarily focus on overall FDI, the main innovation of this study lies in the explicit definition and precise identification of renewable energy FDI among various types of FDI. We manually screen and identify renewable energy FDI projects worldwide to construct a firm-level global dataset covering 185 sovereign countries from 2003 to 2023, which is then matched with electricity generation data from the U.S. Energy Information Administration. This enables a systematic examination of the mechanisms through which renewable energy FDI contributes to the green transition of the global power system.

Our findings remain consistent and significant across various model specifications and robustness checks. Based on the static two-way fixed effects model, the estimates show a statistically significant positive association between renewable energy FDI and both renewable electricity generation and its share in the power mix. In addition, by employing the system GMM dynamic panel model and instrumental variable approach, we alleviate potential endogeneity concerns arising from the possibility that countries with faster green transition processes may themselves attract more foreign investment.

The heterogeneity analysis reveals that the diversification of electricity generation sources provides additional momentum for the green transition, gradually facilitating the substitution of fossil fuels with renewable energy. Among different energy types, renewable energy FDI exerts the most significant marginal effects on wind and solar power, indicating its crucial role in promoting the diversification of clean energy development, whereas its impact on biomass energy is relatively weaker. Furthermore, the technological effect of renewable energy FDI is found to be more pronounced in high-income countries.

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This may be attributed to several factors, including the fact that high-income economies typically possess more advanced power infrastructure, well-established environmental governance systems, and greater capacity to leverage cutting-edge technologies and financial resources through foreign direct investment. At the project level, this study documents an interesting finding: different types of renewable energy FDI projects exert varying impacts on both the green transition of the electricity sector and the creation of new employment opportunities. The results indicate that expansion and co-location projects exhibit larger short-run coefficients for renewable electricity outcomes and employment than new projects. This suggests that expansion projects can capitalize on existing electricity infrastructure to achieve rapid capacity scaling and optimize the green composition of the power mix, while co-location projects take advantage of existing geographic locations, resources, and technological assets to exhibit higher capital conversion efficiency. This finding is consistent with IRENA's (2023) emphasis on an "efficiency-oriented reinvestment pathway", particularly suitable for countries and regions with well-established institutions and stable policy environments. In contrast, while greenfield projects hold important strategic value in the medium to long term, they typically involve longer construction cycles, create fewer new jobs, and yield lower short-term returns. Therefore, when formulating future policies on renewable energy FDI, countries should consider the project life cycle, underlying infrastructure conditions, and policy environment in a comprehensive manner, to better realize the scale effects of investment. By doing so, they can not only safeguard long-term strategic objectives but also ensure better alignment between project types and timeliness, thereby achieving dual optimization in resource allocation and green transition (World Bank, 2023).

As shown by Xu and Sun (2025), heterogeneity across groups is critical for the effectiveness of policy interventions. For developing countries, improving internet penetration, institutional quality, and the rule of law may enhance their capacity to attract and utilize renewable energy FDI, thereby accelerating the energy transition and creating jobs. For developed countries, renewable energy FDI can further stimulate technology spillovers and innovation activities, supporting long-term green growth. At the global level, the positive role of renewable energy FDI not only aligns with the United Nations Sustainable Development Goals but also holds significant importance for fostering a more inclusive and sustainable global energy transition.

This study has several important limitations that should be acknowledged. First, our analysis draws exclusively on greenfield investment records from the *fDi Markets* database, and cross-border mergers and acquisitions in renewable energy are not incorporated into our empirical setting. As a result, we cannot capture the full scope of cross-border renewable energy FDI. Second, while we isolated renewable energy FDI, we did not disaggregate it into specific sub-sectors (e.g., wind, solar, or biomass). This limits our capacity to evaluate the heterogeneous effects of diverse green capital flows. Third, despite deploying system-GMM and instrumental variable specifications to alleviate endogeneity risks, observational panel data cannot fully rule out omitted-variable bias or reverse causality. Fourth, our analysis focuses on aggregate country-level outcomes. We cannot capture within-country regional disparities. Accordingly, future research can advance this work in multiple directions. Further work may integrate M&A transaction data to compare greenfield and brownfield renewable energy investment impacts. Subsequent studies may also adopt finer sub-sector classifications and sub-national regional data. More granular identification strategies are needed to sharpen causal inference and disentangle the exact transmission mechanisms linking cross-border renewable energy capital inflows to power-sector decarbonization.

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Declaration of competing interest

Declaration of interests

☑The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability statement

The electricity-generation dataset analysed in this study is publicly available from the U.S. Energy Information Administration (EIA). The renewable energy foreign direct investment micro-project dataset is extracted from *fDi Markets* (Financial Times Ltd), a commercial proprietary database under institutional licence. Complete variable definitions, data-processing protocols, and Stata analysis scripts used for estimation are provided as supplementary materials accompanying this manuscript. Qualified researchers may obtain access to *fDi Markets* via institutional subscription. All aggregated descriptive statistics are reported within the article tables.

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