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Enhancing energy transition: The role of private foreign investment and aid in developing nations☆

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ABSTRACT

Private foreign investment and aid have emerged as critical channels through which the world tackles climate change. Over the years, wealthy individuals and organisations have significantly contributed to various sustainability initiatives, with a particular focus on advancing sustainable energy. This paper investigates the impact of private foreign investment and aid on energy transition initiatives in developing countries using a large sample of 102 developing countries from 1990 to 2021. Our results indicate that private foreign investment and aid are positively associated with sustainable energy production. Further analyses reveal that this impact is more pronounced in countries with low perceived corruption, while financial crises exert negative impact on the relationship. Continental analysis shows that countries in the African and American regions benefit more from private foreign investment than other continents. Our findings are robust to the alternative measurement of variables and econometric models, including the two-step system generalised method of moments. Based on the findings, we recommend that developing countries strengthen their institutional and governance structures to attract greater private financial inflows to boost efforts towards energy transition.

1. Introduction

The increasing waves of extreme weather conditions, coupled with the high demand for energy even at the household level, have put the world at a crossroads. On the one hand, high energy consumption is a significant source of high carbon emissions (Bianco et al., 2019; Oladokun and Odesola, 2015; Zhu et al., 2016). On the other hand, there is an increasing demand for energy and the world is more energy-dependent than ever due to the reliance on technology (Dokas et al., 2022; Paramati et al., 2018; Sarkodie and Adom, 2018). The complex relationship between energy consumption and climate change means that cutting down energy consumption is nearly impossible. Hence, countries should focus on mechanisms for transitioning towards cleaner and more sustainable energy. While sustainable and clean energy is good for the climate and the environment, it is often expensive, particularly at the initial stages and might take a long time to implement (Singh et al., 2023; Srirangan et al., 2012). As a result, many developing countries are falling behind in the production of sustainable energy. Most sustainable energy production, such as solar, hydro, nuclear, wind power and biomass, requires huge initial capital investment and most developing countries do not have such financial resources (Aluko et al., 2023; Singh et al., 2023; Srirangan et al., 2012). In response to the lack of investment in developing countries, some wealthy foreign individuals and corporations have, over the years, committed a lot of private investment and aid to the energy sector of these countries (OECD, 2021). For instance, Bill Gates have made significant donations to support the electrification of Africa (Forbes, 2019). The World Bank's Climate Change Action Plan (CCAP) highlights how private investments and climate finance are being mobilized to accelerate renewable energy deployment in developing economies (World Bank, 2023b). However, given the mixed findings on the impact of foreign investment and aid on economic growth and development in recipient countries (Doucouliagos and Paldam, 2009; Hansen and Tarp, 2000), there are increasing concerns that their private aid and investment in the energy sector are less likely to

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improve sustainable energy production. Therefore, it warrants empirical investigations to understand the influence of private investment and aid on energy transition in developing countries. We posit that private investment and aid to the energy sector has some unique quality and is likely to achieve different outcomes compared with other forms of foreign investment and aid to all sectors.

Private foreign investment plays a crucial role in accelerating sustainable energy transitions, enabling the deployment of clean technologies, infrastructure improvements and market expansion (Zhuang et al., 2025). By channeling financial resources into renewable energy sectors, private investors facilitate advancements in solar, wind, and energy storage innovations, fostering competition and accelerating the shift away from fossil fuels (Zhuang et al., 2025). Investment from private organisations not only enhances energy security but also supports the development of smart grids and efficient transmission networks, crucial for integrating renewables into the energy mix (Clastres, 2011; Battaglini et al., 2009). Despite these benefits, private investment faces challenges that can limit its effectiveness. Many investors prioritize short-term financial gains over long-term sustainability objectives, leading to underinvestment in renewable energy due to concerns over market volatility and uncertain profitability (Chiappinelli and May, 2022). Furthermore, greenwashing, where companies exaggerate their sustainability initiatives, has raised concerns about transparency and accountability (Laufer, 2003). High upfront costs and regulatory inconsistencies further deter private financial flows, particularly in developing economies, where unstable policy environments add to investment risks (Chen et al., 2024a, 2024b).

Foreign aid, on the other hand, has faced significant criticism for poor management, political motivations and lack of targeted impact in addressing critical issues like sustainable energy production (Doucouliagos and Paldam, 2009). In response, private donors, including wealthy individuals such as Bill Gates and Jeff Bezos, have directly funded specific energy projects in developing countries, aiming for better oversight and transparency (Harms and Lutz, 2006; Bezos Earth Fund, 2020). Unlike traditional aid, private donations are less influenced by political interests and typically target specific projects, reducing risks of diversion and inefficiency (Boone, 1996; European Commission, 2018). Furthermore, stronger transparency and accountability mechanisms often associated with private aid may enhance its effectiveness compared to state-funded assistance (Hale, 2008; Esser and Bench, 2011). However, private aid is not immune to mismanagement and sustainability concerns. Previous studies indicate that foreign aid, whether public or private, has struggled to bridge development gaps in many recipient countries (Boone, 1996; Doucouliagos and Paldam, 2009). Additionally, business-oriented donors may prioritize profit expansion over genuine sustainability, potentially using aid to increase energy consumption rather than promote renewable sources (Hansen and Tarp, 2000). Weak regulatory oversight in many developing nations further exacerbates mismanagement risks, emphasizing the need for robust governance structures to ensure effective aid utilization (Bräutigam and Knack, 2004). While private aid holds promise, it requires careful scrutiny and structured policy frameworks to maximize its impact on sustainable energy transitions.

Based on the above contrasting arguments on the impact of private investment and aid on sustainable energy production, this paper seeks to examine the relationship between private investment and aid and sustainable energy production in developing countries. We use a large sample of 102 developing countries between 1990 and 2021. Consistent with prior studies (Aluko et al., 2023), our data on sustainable energy production is sourced from the Sustainable Energy for All Initiative. Sustainable energy production is measured as percentage of total energy production. Data on private investment and aid to the energy sector is collected from OECD statistics. We employ the Two-Step System Generalised Method of Moments (GMM) to ensure reliable and efficient estimations.

Our baseline results show a positive and significant impact of private foreign investment and aid on sustainable energy production with the effect being more pronounced for private foreign investment. The results suggest that countries receiving high levels of foreign private investment and aid experienced significant increases in sustainable energy production. Given the influence of corruption on foreign investment and aid distribution, we further examine whether corruption dampens or amplifies the impact of private foreign aid and investment on sustainable energy production. Our findings reveal that corruption dampens the positive impact of foreign private aid and investment on sustainable energy production and limits their effectiveness in corrupt developing countries compared with less corrupt nations. Additionally, aid effectiveness literature has established that some regions has experienced significant economic growth and development due to foreign aid, while others are still lacking behind despite receiving levels of foreign aid (Doucouliagos and Paldam, 2009; Dreher et al., 2018; Hansen and Tarp, 2000). Hence, the impact of private aid and investment on sustainable energy production may differ from region to region. Our continental analyses show that the positive effect of private investment and aid on sustainable energy is more pronounced in Africa and the Americas compared with Europe. These results indicate that the continental location of the recipient country can significantly influence the role of private foreign investment and aid shaping energy transition in developing countries and the achievement of the Sustainable Development Goals (SDGs).

Our study makes significant contributions to literature and policy in several ways. First, we contribute to the academic debate on the sources of financing energy transition initiatives in developing countries (Aluko et al., 2023; Aziz and Jahan, 2023; Fleta-Asín and Muñoz, 2021). Although almost all developing countries are committed to achieving the Sustainable Development Goals and Sustainable Energy for All Initiative, they lack the financial resources to bring this initiative to reality. For instance, the International Energy Agency (IEA) estimates that the achievement of the Sustainable Energy for All Initiative will require an investment of about $50 billion (Aluko et al., 2023). Arguably, most developing countries cannot afford to commit their scarce resources to this initiative even though there is a willingness to the initiative. Further, given the rising debt and its consequences on many developing economies, our results are timely in highlighting the benefits of foreign private aid and investment in sustainable energy production. Our findings, therefore, provide crucial new empirical evidence to support policy formulation on finding alternative sources of funding for sustainable energy production.

Second, our study also contributes to the national governance literature by providing new insights into how national institutional structures, such as corruption, shape the effectiveness of private foreign investment and aid in energy production (Bauhr et al., 2013; Boateng et al., 2021; Boateng et al., 2024; Krasniqi and Demukaj, 2021; Tavares, 2003; Yu et al., 2022). Prior studies on foreign aid and corruption have largely focused on donor and recipient countries. While private foreign aid and investment may have good implementation and monitoring structures on their funded projects, they still need an effective and stable institutional environment to achieve their goals. Given the varying levels of corruption in developing countries, it is crucial to understand how corruption shapes the impact of foreign private aid and investment on sustainable energy production. As our results indicate, corruption hampers the effectiveness of private investment and aid on sustainable energy production. Hence, our findings underscore the importance of improving governance in developing countries to attract more private foreign investment and aid and fully harness its benefits for increasing sustainable energy production.

Third, this paper directly addresses the commitment of developing countries to the Sustainable Energy for All initiative, which was launched in 2011 with the aim of achieving universal access to electricity by 2030. Our findings highlight the significance of foreign private investment and aid in augmenting the efforts of developing countries to honour their commitment to this initiative. Further, our findings provide

valuable policy implications for international investors and donors that their funding towards sustainable energy and, by extension, to the attainment of Sustainable Development Goals can yield significant positive outcomes. Such positive outcomes are particularly viable in developing countries with low levels of corruption, as these environments are more conducive to effective and efficient implementation and monitoring of funded projects.

The remainder of the paper is structured as follows. Section 2 outlines theoretical background and motivation and Section 3 reviews the relevant literature and develops the hypothesis. Section 4 outlines the methodology. Section 5 contains the findings and discussions on the empirical results. The paper concludes in Section 6 with policy implications and suggestions for future research.

2. Theoretical background and motivation

The theoretical framework for foreign private investment draws from the neoclassical growth theory (Solow, 1999) and endogenous growth theory (Romer, 1990). According to neoclassical growth theory (Solow, 1999), long-run economic growth is primarily driven by capital accumulation, labour force growth, and technological progress. In this framework, foreign private investment serves as a critical channel for increasing a country's capital stock, particularly in capital-scarce developing economies. Foreign private investment contributes to sustainable energy production by injecting financial resources that facilitate the development of renewable infrastructure. Since many developing countries face limited domestic savings and weak public investment capacity, private foreign capital helps bridge the investment gap essential for scaling up clean energy technologies. Similarly, endogenous growth theory (Romer, 1990) posit that foreign investment can enhance productivity and innovation through technology transfer and capital accumulation, particularly in sectors like renewable energy that require high upfront costs and technical expertise (Romer, 1990; Borensztein et al., 1998). Foreign direct investment is seen as a catalyst for scaling up clean technologies, improving infrastructure, and fostering competition in energy markets (UNCTAD, 2023).

The energy sector is a critical leverage point for achieving both sustainable development and climate goals. Energy generation and consumption account for over two-thirds of global greenhouse gas emissions (International Energy Agency (IEA), 2021), making the transition towards renewable sources indispensable for meeting the Paris Agreement targets and the Sustainable Development Goals (SDGs). Unlike many other sectors, the energy transition requires substantial upfront capital investments, long-term financial commitments, and governance frameworks that can mitigate regulatory and technological risks (Tian et al., 2022). These characteristics create a compelling rationale to investigate how private foreign investment and aid can accelerate renewable energy production. By directing financial flows into this sector, private actors not only facilitate technological innovation and economic transformation but also address the environmental urgency of climate change. Thus, the energy sector provides a uniquely suitable context to motivate the study of private finance as a driver of both economic resilience and planetary sustainability.

However, the effectiveness of private investment and aid in advancing the energy transition depends heavily on institutional and financial channels. On the institutional side, regulatory clarity, contract enforcement, low corruption, and policy stability shape investor confidence and the successful deployment of renewable technologies (Daude and Stein, 2007; Hoang et al., 2021). Weak institutions can lead to project delays, rent-seeking behaviour, and misallocation of resources, diminishing the developmental impact of investment and aid. On the financial side, well-functioning credit and capital markets are critical for absorbing and channeling private flows efficiently. In contexts of underdeveloped financial systems, foreign investment may fail to integrate with domestic economies, while financial crises can further constrain credit availability, destabilise markets, and weaken the investment–energy transition nexus (Aghion et al., 2005).

The academic debate on foreign aid effectiveness remains polarized between two dominant theoretical perspectives. The political economy view, recently refined by Dreher et al. (2024), argue that aid primarily serves as an instrument for donors to advance geopolitical and economic interests, often aligning with the strategic priorities of donor nations rather than recipient needs. In contrast, the institutional critique, articulated in contemporary work by Dijkstra (2018), contends that aid inflows frequently create rent-seeking opportunities for domestic elites in recipient countries, distorting local incentives and undermining developmental outcomes. However, these established frameworks focus predominantly on traditional public aid flows, leaving the theoretical distinctiveness of private foreign investment and aid, particularly within renewable energy transitions, underexplored.

Emerging theoretical literature highlights that private investment and aid operate under fundamentally different incentive structures compared to state-led aid. While public aid is often shaped by diplomatic and political considerations (Dreher et al., 2024), private investment and aid from philanthropic foundations and impact investors focus on measurable outputs and technological solutions driven by both mission alignment and reputational accountability mechanisms (Zolfaghari and Hand, 2023). This theoretical distinction is particularly salient in energy transition financing, where the project-based nature of interventions aligns with Ostrom's principles of polycentric governance, allowing multiple stakeholders to coordinate around specific, bounded initiatives rather than navigating the complexities of national systems (Thiel, 2023).

The theoretical case for private investment and aid in accelerating sustainable energy production draws on three interrelated propositions. First, the principal-agent dynamics differ fundamentally from public aid models, with shorter accountability chains between funders, implementers, and beneficiaries (Basak and van der Werf, 2019). Second, the technological specificity of energy projects enables verifiable impact pathways where outputs like megawatts installed or emissions reduced can be objectively measured (Zhang, 2022). Third, the growing integration of market mechanisms in climate finance introduces price signals and competition absent in traditional aid, theoretically improving allocative efficiency (Anbumozhi et al., 2018; Kalirajan and Chen, 2018).

These theoretical distinctions suggest that private investment and aid may overcome several well-documented inefficiencies in public aid systems. Whereas traditional aid suffers from sovereignty paradox, such as the tension between donor influence and recipient ownership, private investment and aid operate within technical assistance frameworks (Brown, 2013). Furthermore, corporate involvement introduces market discipline mechanism, where continued funding depends on achieving predefined performance benchmarks (Bracking and Leffel, 2021). Thus, private investment and aid diverge substantially from conventional donor-driven models, offering a more flexible, accountable, and impact-driven approach to development financing. This distinction is particularly relevant in the context of sustainable energy, where efficiency, governance, and technological advancements play a crucial role in driving long-term success.

3. Empirical review and hypotheses development

Recent empirical research highlights the growing role of private foreign investment and aid in accelerating energy transition across developing economies, offering both significant opportunities and notable challenges (Li et al., 2022). Unlike traditional public aid, private financing, which is channelled through philanthropic foundations, impact investors and corporate social responsibility initiatives, demonstrates distinct advantages in efficiency, flexibility and innovation (Halme and Laurila, 2009). However, its effectiveness remains highly dependent on local institutional and market conditions. A 2025 World Bank study analysing 120 renewable energy projects in Sub-Saharan

Africa found that privately funded initiatives achieved implementation timelines that were 28 % faster and unit costs that were 19 % lower compared to public-sector projects, largely due to leaner decision-making structures and performance-linked financing (World Bank, 2025). Aluko et al. (2023) examined the effect of foreign direct investment on electricity access in Africa and highlight the growing importance of foreign investment in the energy sector of developing countries. Cheng et al. (2021) focused on the impact of public-private partnership investments in China, revealing that these investments have helped reduce carbon emissions. Similarly, Chu et al. (2024) reported that public-private partnerships effectively reduce carbon emission in E7 countries. This study demonstrates the potential of collaborative efforts between the public and private sectors in achieving environmental goals. Additionally, Brunnschweiler (2010) explored the role of the financial sector in renewable energy development in developing and transition economies. The findings suggest that well-functioning financial markets play a critical enabling role by reducing capital constraints, lowering the cost of financing, and facilitating risk-sharing mechanisms, all of which are essential for supporting long-term investments in renewable energy infrastructure.

Despite these compelling arguments for the positive effect of private investment and aid on sustainable energy production, a growing strand of literature cautions against overly optimistic conclusions. Some studies suggest that these interventions may have insignificant or even negative impacts on sustainable energy production (Amin et al., 2021). Prior research highlights that the effectiveness of private investment and aid is often contingent upon the presence of regulatory reforms and institutional support. For example, Amin et al. (2021) find that the impact of private investment on energy consumption becomes significant only in contexts where substantial energy sector reforms have been implemented. This divergence of findings underscores a central tension in the literature. On the one hand, private investment and aid can accelerate energy transition when supported by robust governance and well-functioning financial markets. On the other hand, their effectiveness may be undermined in contexts characterised by corruption, poor governance, and lack of transparency (Kolstad and Wiig, 2009). Such inconsistencies point to the critical role of institutional and market conditions in shaping outcomes private financial flows.

By engaging with these divergent perspectives, our study contributes to the literature by systematically investigating how private investment and aid interact with institutional quality and financial environments to influence renewable energy transition in developing economies. Specifically, we highlight that the effectiveness of private finance in energy transition is not universal but conditional upon these enabling environments. Based on these theoretical and empirical perspectives, we propose the following un-directional hypothesis:

H1: *Foreign private investment and aid significantly affect sustainable energy production in developing countries.*

4. Methodology

4.1. Sample selection and data sources

This study focuses on developing countries. We begin our sample from all developing countries as classified and defined by the United Nations and World Bank Economic Outlook Report. Currently, there are over 160 jurisdictions classified as emerging and developing countries (World Development Indicators). Countries with a large amount of missing data were excluded from the sample. Furthermore, the number of sample countries is limited due to data availability on sustainability energy production and private foreign investment and aid. The final sample consists of 2451-year country observations from 102 developing countries between 1990 and 2021. We collect data from reputable sources such as the World Development Indicators, World Governance Indicators, OECD statistics and Sustainable Energy for All Initiatives.

4.2. Variable measurement

4.2.1. Dependent variable

Sustainable energy production. In 2011, in an effort to enhance the achievement of the Sustainable Development Goals, the United Nations and other development agencies established the Sustainable Energy for All Initiative (SEforALL, 2022). The aim of this initiative is to increase the production and access to sustainable energy across the globe with particular attention to developing countries (SEforALL, 2022). As part of this initiative, data on access and production of sustainable and renewable energy has been collected over the past decades. Consistent with prior studies (Aluko et al., 2023), we collect data on sustainable energy production from the Sustainable Energy for All Initiative hosted by the World Bank. To mitigate the potential effect of the overall energy production in the country, the variable is measured as the proportion or percentage of the total energy production. Our measure of sustainable energy production comprises mainly of renewable electricity supply. We focus on electricity because it is the dominant energy source for utilities in developing countries, accounting for approximately 58–72 % of modern energy consumption (International Energy Agency, 2022; International Energy Agency, 2023). This aligns with findings from World Bank (2023), which highlight that electricity is the primary driver of energy access and economic development in low- and middle-income nations.

4.2.2. Independent variable

Consistent with prior studies (Desai and Kharas, 2018; Schweinberger and Lahiri, 2006), we measure private foreign investment and aid based on the total amount of private foreign investment, aid and philanthropic contributions received by the sample countries. The data is sourced from the OECD statistics on aid (OECD, 2024). Specifically, private foreign investment is the sum of geographical distribution of bilateral disbursements of private flows to developing countries undertaken by firms and individuals residing in the reporting country. This category includes large-scale corporate investments in energy infrastructure, such as solar and wind farms. Private foreign aid is the sum of philanthropic donations and aid for project-level development in the recipient country by over 40 of the largest private philanthropic foundations working for development (OECD, 2024). This includes contributions from organisations such as the Gates Foundation and other philanthropic entities supporting sustainable energy initiatives. To analyse the combined and individual effects, we present three regressions to show different impact of private investment and private aid on the sustainable energy transition. It is important to note that the OECD distinction between these sources began in 2013, and our dataset reflects this classification accordingly. Additionally, to mitigate the potential bias caused by country size, we deflate the financial figures by total gross domestic product (GDP). Furthermore, we transform the data into its natural logarithm form as an alternative measurement.

4.2.3. Control variables

Consistent with prior studies, we control for other factors that are likely to influence the production of sustainable energy utilities in the country (Abbas et al., 2023; Aluko et al., 2023; Aziz and Jahan, 2023; Chen et al., 2024a, 2024b). We include GDP per capita and GDP growth to control economic development and economic growth respectively. Countries with high GDP per capita and GDP growth are likely to experience high sustainable energy production because such countries will have the resource capacity to invest the necessary financial capital. We also include foreign direct investment and trade openness to control the potential impact of foreign capital on the production of sustainable energy. Prior studies have established that foreign direct investment positively impacts access and production of sustainable energy (Aluko et al., 2023). We also include carbon emissions and energy consumption to mitigate the impact of environmental-related factors (Chen et al., 2024a, 2024b). We expect countries with high carbon emissions and

energy consumption to have high sustainable energy utility production as a means of improving their environmental footprint. The detailed variable measurements and sources are shown in Table 1.

4.3. Econometric model

To address the challenges associated with the nature of the dataset, we employ pooled group mean ordinary least squares (OLS) as the primary estimator. This choice is informed by several methodological and practical considerations. First, the stickiness of the dependent and independent variables—such as sustainable energy production and private foreign aid—suggests that these variables exhibit persistence over time. In such cases, pooled regression offers a viable approach by leveraging both cross-sectional and time-series variations, allowing for a more comprehensive analysis of the relationships. Additionally, pooled regression is robust when variables exhibit low temporal variability, as it pools information across all units to enhance statistical power (Baltagi, 2008). Second, the high incidence of missing data within the sample necessitates an estimator that can manage unbalanced panels effectively. The pooled group mean OLS estimator is particularly suitable because it does not impose strict requirements for balanced data, unlike more sophisticated techniques such as dynamic panel regressions, which might further exacerbate issues with missing observations (Wooldridge, 2010). By pooling observations, this method ensures that the maximum available information is utilised, thereby mitigating the impact of missing data on the robustness and reliability of the results. We specify our model as follows:

$$\begin{aligned} Sustainable\ energy\ production_{it} = {} & a + \beta_1 Private\ foreign\ investment\ and\ aid_{it} \\ & + \beta_2 GDP\ per\ capita_{it} + \beta_3 GDP\ growth_{it} \\ & + \beta_4 Trade\ openess_{it} \\ & + \beta_5 Foreign\ direct\ investment_{it} \\ & + \beta_6 Carbon\ emission_{it} \\ & + \beta_7 Energy\ consumption_{it} + \varepsilon_{it} \end{aligned} \quad (1)$$

Where *Sustainable energy production* represents the total amount of renewable electricity output as the percentage of total electricity supplies, *Private foreign investment and aid* is the total amount of private investment and aid from individuals and firms in foreign countries for development in recipient country. It is measured as a ratio of GDP or natural logarithm format. *GDP* per capita is natural log of gross domestic product (GDP) divided by midyear population. *GDP growth* is annual percentage growth rate of GDP at market prices based on constant local currency. *Trade openness* is the sum of export and import as a percentage of GDP. *Foreign direct investment* are the net inflows of investment as percentage of GDP. Carbon emissions is the natural log of carbon dioxide emission stemming from the burning of fossil fuels and the manufacture of cement per GDP per capita. *Energy consumption* refers to use of primary energy before transformation to other end-use fuels per GDP per capita. ε_{it} is the error term.

5. Empirical results

5.1. Descriptive statistics

The descriptive statistics of the variables used in the study are presented in Table 2. These statistics include the mean, standard deviation, 25th percentile, 50th percentile and 75th percentile. The mean value of private foreign investment and aid is $1060 million, suggesting that the average amount of private foreign investment and aid received by developing countries over the sample period is $1060 million. However, we observe a large variation among the sample countries. The 25th percentile is $11.41 million, which is just about 1 % of the mean, highlighting the high concentration of capital flows among a few recipient countries. Private foreign investment has a slightly higher

Table 1
Variable measurements and sources.

Variable name	Description	Sources
Sustainable Energy production	Total amount of renewable electricity output as the percentage of total electricity supplies. Renewable electricity share of total electricity output (%): Electricity generated by power plants using renewable resources as a share of total electricity output.	Sustainable Energy for All Initiatives at World Bank
Private foreign investment and aid	The sum of private investment and aid from individuals and firms in foreign countries for development in recipient country.	OECD statistics
Private foreign investment	The sum of geographical distribution of bilateral disbursements of private flows to developing countries undertaken by firms and individuals residing in the reporting country.	
Private foreign aid	The sum of philanthropic donations and aid provided by over 40 of the largest private philanthropic foundations, aimed at supporting project-level development initiatives in the recipient country.	
GDP per capita	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars. Data is normalised using the log format.	World Development Indicators
GDP growth	Annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.	World Development Indicators
Trade openness	The sum of export and import as a percentage of gross domestic product.	World Development Indicators
Foreign direct investment	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 % or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign	World Development Indicators

(continued on next page)

Table 1 (*continued*)

Variable name	Description	Sources
	investors, expressed as a percentage of GDP.	
Carbon emissions	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during the consumption of solid, liquid, gas fuels and gas flaring.	World Development Indicators
Energy consumption	Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.	World Development Indicators

Table 2
Summary statistics.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	mean	sd	p25	p50	p75
Private foreign investment & aid ($ millions)	1060	3864	11.41	71.89	422.1
Private foreign investment & aid(%GDP)	0.181	0.102	0.120	0.189	0.253
Private foreign investment & aid (Log)	4.310	2.617	2.587	4.347	6.080
Private foreign investment ($ millions)	1076	3895	11.87	72.12	426.8
Private foreign investment (% GDP)	0.190	0.103	0.128	0.200	0.264
Private foreign investment (Log)	4.573	2.691	2.820	4.617	6.410
Private foreign aid ($ millions)	22.64	58.11	0.799	3.097	15.21
Private foreign aid (%GDP)	0.0431	0.0991	0.0079	0.0492	0.114
Private foreign aid (Log)	1.075	2.428	−0.219	1.139	2.725
Sustainable energy production	37.77	35.71	2.281	28.87	68.26
Renewable energy consumption	44.59	31.50	13.96	42.61	75.73
Trade openness	73.18	38.47	45.95	64.92	91.46
Foreign direct investment	3.880	6.822	0.817	2.325	4.993
GDP growth	3.918	6.684	1.700	4.156	6.414
GDP per capita	7.368	1.152	6.503	7.369	8.293
Carbon emission	0.170	1.378	0.0084	0.107	0.914
Energy consumption	3.065	1.257	2.444	3.137	3.807

Note: This table presents the descriptive statists of the variables used in the regression analysis. The statistics include the mean, standard deviation, 25th, 50th and 75th percentile. Variable description and sources are presented in Table 1.

mean of $1076 million with the 25th percentile and median values are $11.87 million and $72.12 million, respectively, again indicating that while some countries receive substantial investment flows, many receive very limited amounts. In contrast, private foreign aid exhibits a much lower mean of $22.64 million, with the 25th percentile is only $0.799 million, and the median is $3.097 million, reflecting the relatively small and highly concentrated nature of private foreign aid flows within the sample. Regarding the dependent variable, sustainable energy production, the mean of 37.77 indicates that over the sample period, the sample countries generate about 37.77 % of their utility energy from sustainable sources. Similarly, to foreign private investment and aid, we observe large variation across the sample countries and period as evidenced by low 25th percentile and high standard deviation. The descriptive statistics of the control variables are consistent with past studies (Abbas et al., 2023; Aluko et al., 2023; Aziz and Jahan, 2023; Chen et al., 2024a, 2024b) and consistent with the characteristics of developing countries.

We perform Pearson correlation matrix to determine the possibility of multicollinearity. Prior studies establish a standard threshold of 0.8, beyond which there is a potential threat of multi-collinearity (Field, 2000; Tabachnick and Fidell, 2013). The results of the Pearson correlation matrix are presented in Table 3. None of the correlation coefficients is above the standard threshold. Hence, our sample data is suitable for regression estimation. In addition to the Pearson correlation matrix, we also calculate the variance inflation factor to confirm the non-existence of multi-collinearity in the sample. For brevity, the results are un-tabulated.

5.2. Baseline results

The baseline results are presented in Table 4. To account for the persistence of the dependent variable, we apply the pooled group mean estimator. Consistent with previous studies (Alam et al., 2019; Gong et al., 2023), we include country and year effects to control for the potential effect of the country and time-variant. The coefficient of private foreign investment and aid in Column (1) is positive and statistically significant, indicating that private foreign investment & aid contribute significantly to sustainable energy production in developing countries. Specifically, a one-unit increase in combined private investment and aid is associated with a 7.367 % increase in sustainable energy production in developing countries. Compared to other forms of foreign aid, private foreign aid and investment are less likely to be influenced by diplomatic and political interests, hence, ensuring greater efficiency in management and monitoring. Additionally, most private foreign investment and aids are targeted at specific projects, ensuring its effectiveness. For instance, the private foreign investment aid used in this study is specifically allocated for the energy sector. Projects in specific sectors tend to be small and easier to implement and monitor with less recipient government interference. Furthermore, most of these private aids are donated by big corporations and business people (OECD, 2024). Therefore, these aids and investments are extensions of their regular business activities, and hence, proper implementation and effective monitoring will be necessary to realise the project aim. Unlike other forms of foreign aid, private aid and investment are unique and more likely to be effective in developing countries.

While private foreign investment and aid exhibit a moderate positive effect, the statistical significance in Column (1) is only marginal ($p < 0.10$), suggesting that the synergy between investment and aid requires further verification. Therefore, we test the impact of private foreign investment and aid on sustainable energy production separately, and the results are presented in columns 2 and 3 of Table 4. The coefficient of private foreign investment is larger and highly significant (11.091**) than both combined sources and aid. This suggests that investment is a more effective driver of sustainable energy production than aid. Private foreign aid, however, has a smaller and statistically insignificant coefficient (4.451), likely due to the limited number of observations or the fact that aid alone lacks the scalability of private investment. Investment is approximately 2.5 times more impactful than aid (11.091 vs 4.451), suggesting that private investment tends to focus on high-impact projects such as utility-scale renewables, while aid may suffer from inefficiencies such as administrative overhead or misallocation.

The results of control variables are largely consistent with expectations and prior studies. For instance, GDP per capita has a positive and significant association with private foreign aid and sustainable energy production. However, we find a negative and significant impact of carbon emissions and energy consumption on sustainable energy production. This is probably due to the fact that economies heavily reliant on fossil fuels (high CO_2 emissions) have entrenched infrastructure (coal plants, oil refineries) and vested interests resisting transition (Pfeiffer et al., 2016). For example, countries with large coal industries (e.g. India) face political and economic barriers to adopting renewables (Luthra et al., 2015). Similarly, energy-intensive economies often meet demand with coal and gas rather than renewables because fossil plants can ramp up faster to meet peak demand than renewable sources.

Table 3
Correlation matrix.

	1	2	3	4	5	6	7	8	9	10
1.Sustainable Energy Production	1									
2. Private Investment and aid	0.01**	1								
	(0.07)									
3.Private foreign investment	0.03**	0.79***	1							
	(0.02)	*(0.00)*								
4.Private foreign aid	0.09**	0.28***	0.2***	1						
	(0.04)	*(0.00)*	*(0.00)*							
5.GDP per capita	0.23***	0.38***	0.41***	−0.27***	1					
	(0.00)	*(0.00)*	*(0.00)*	*(0.00)*						
6.GDP growth	0.01	0.04**	0.04*	0.08***	−0.03	1				
	(0.89)	*(0.02)*	*(0.08)*	*(0.01)*	*(0.11)*					
7.Trade openness	−0.17***	−0.01	−0.01	−0.32***	0.29***	0.04***	1			
	(0.00)	*(0.71)*	*(0.73)*	*(0.00)*	*(0.00)*	*(0.013)*				
8.Foreign direct invest	−0.11***	0.03*	0.07***	−0.04	0.09***	0.2***	0.37***	1		
	(0.00)	*(0.09)*	*(0.18)*	*(0.00)*	*(0.00)*	*(0.00)*	*(0.00)*			
9.Carbon emission	−0.34***	0.37***	0.41***	−0.27***	0.77***	−0.01	0.35***	0.11***	1	
	(0.00)	*(0.00)*	*(0.00)*	*(0.00)*	*(0.00)*	*(0.43)*	*(0.00)*	*(0.00)*		
10. Energy consumption	−0.16***	0.25***	0.3***	−0.01	0.5***	−0.06***	0.21***	0.02	0.53***	1
	(0.00)	*(0.00)*	*(0.00)*	*(0.84)*	*(0.00)*	*(0.00)*	*(0.00)*	*(0.32)*	*(0.00)*	

Notes: This table presents the Pearson's correlations coefficients for all the variables. Table 1 provides detailed definitions of the variables.

Table 4
Baseline results.

	(1)	(2)	(3)
VARIABLES	SEP	SEP	SEP
Private foreign investment & aid	7.367*		
	(1.808)		
Private foreign investment		11.091**	
		(2.293)	
Private foreign aid			4.451
			(0.549)
GDP per capita	−2.179**	−1.716	−0.130
	(−2.047)	(−1.407)	(−0.037)
GDP growth	−0.148***	−0.032	0.172*
	(−2.878)	(−0.514)	(1.680)
Trade openness	0.047***	0.043**	0.003
	(2.823)	(2.196)	(0.059)
Foreign direct investment	0.108*	0.047	−0.089
	(1.648)	(0.642)	(−0.899)
Carbon emission	−5.457***	−4.462***	−13.845***
	(−4.659)	(−3.267)	(−4.328)
Energy consumption	−3.175***	−3.353***	10.273***
	(−7.028)	(−6.707)	(4.681)
Constant	131.639***	126.600***	−4.637
	(15.992)	(13.593)	(−0.145)
Country effect	Yes	Yes	Yes
Year effect	Yes	Yes	Yes
Observations	2004	1458	493
R-squared	0.926	0.929	0.968

Notes: This table presents the pool regression estimations of the impact of private investment & aid on sustainable energy production (SEP). The results of Private foreign investment & aid, Private foreign investment and Private foreign aid measured as percentage of GDP are presented in columns 1, 2, and 3 respectively. The dependent variable is measured as sustainable electricity as a percentage of the total electricity production. All the variables are defined in Table 1. t-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.3. Robustness tests

5.3.1. Alternative measurements of dependent and independent variables

We begin the robustness test by employing alternative measurements of dependent and independent variables. The results are presented in Table 5. Columns 1 to 3 contain the results of alternative measurement of the dependent variable, where sustainable energy production (SEP) is replaced by renewable energy consumption (REC). The coefficient of private foreign investment & aid is positive and significant at 1 % level. In columns 3 to 6 of Table 5, we present the results for alternative measurements of private foreign investment and aid (measured as natural log). The results are qualitatively similar to the baseline results, confirming the robustness of the findings.

5.3.2. Endogeneity test

We have conducted pre-regression estimations to select the appropriate modelling technique and considered alternative measurements of the dependent and independent variables. Despite these robust steps in our estimations, we cannot completely rule out the possibility of endogeneity, and hence further attention is required. Arguably, reverse causality is less likely to be an issue. This is because it is less plausible for sustainable energy production to directly drive the flow of private foreign aid into developing countries. However, potential endogeneity may still arise due to the persistence of past values in shaping future outcomes.

To mitigate these concerns, we employ the two-step System Generalised Method of Moments (SGMM). According to Arellano and Bond (1991) and Arellano and Bover (1995), two-step system GMM includes the lagged effect of the dependent variable and also address the issue of weak instrumental variables. This makes the two-step system GMM superior to most econometric models (Tawiah et al., 2022, 2024). The SGMM uses the lag of the dependent variable and control variables as instrumental variables. Our choice of internal instruments is informed by existing literature (Bun and Windmeijer, 2010), which supports the use of lagged internal instruments as valid instruments when the time dimension exceeds ten years. Furthermore, to ensure the robustness and validity of the internal instruments, we perform post-estimation diagnostic tests. For example, the *p*-value of the Arellano-Bond test for autocorrelation is greater than 0.2, confirming no higher-order autocorrelation and instrument validity. Similarly, the p-value of the Hansen test for overidentifying restrictions is greater than 0.3, suggesting no evidence of invalid instruments (Roodman, 2009). The results of the two-step system GMM are presented in Table 6. Similar to the main results, the coefficient of private foreign investment & aid is positive and significant at the 1 % level, indicating the significant influence of private investment and aid on sustainable energy production in developing countries. The findings confirms that private investment & aid play a critical role in fostering sustainable energy production in developing countries.

5.4. The impact of corruption

The relationship between private foreign aid and investment and

Table 5
Alternative measurement of dependent and independent variables.

	Alternative measurement of dependent variable			Alternative measurement of independent variable		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	REC	REC	REC	SEP	SEP	SEP
Private foreign investment & aid	26.499***			2.412***		
	(6.789)			(6.400)		
Private foreign investment		23.483***			1.777***	
		(5.210)			(4.105)	
Private foreign aid			31.304***			−0.610
			(5.184)			(−0.880)
GDP per capita	−0.407	−0.441	3.727***	3.631**	4.010**	12.110***
	(−0.668)	(−0.646)	(3.180)	(2.564)	(2.493)	(3.681)
GDP growth	−0.062	−0.116	0.069	−0.153	−0.056	0.245
	(−0.880)	(−1.393)	(0.496)	(−0.951)	(−0.290)	(0.631)
Trade openness	0.008	0.009	0.004	−0.030	−0.054*	0.028
	(0.832)	(0.772)	(0.251)	(−1.228)	(−1.914)	(0.547)
Foreign direct investment	−0.298***	−0.266***	0.005	−0.166	0.033	0.737**
	(−3.829)	(−2.995)	(0.043)	(−0.869)	(0.153)	(2.511)
Carbon emission	−18.494***	−18.585***	−20.760***	−11.381***	−10.689***	−16.378***
	(−36.853)	(−32.259)	(−22.842)	(−9.493)	(−7.680)	(−6.361)
Energy consumption	−2.507***	−2.027***	−0.553	0.299	0.736	1.362
	(−8.560)	(−6.046)	(−1.149)	(0.436)	(0.903)	(1.056)
Constant	49.975***	52.071***	15.854	5.471	3.374	−71.540*
	(10.030)	(9.028)	(0.861)	(0.475)	(0.251)	(−1.672)
Year effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2451	1770	892	2004	1458	493
R-squared	0.745	0.752	0.722	0.112	0.101	0.131

Notes: This table present the regression analysis of alternative variable of both dependent and independent variables. The alternative independent variables are measured as natural logarithm, while the dependent variable is measured as renewable energy consumption (REC). All the variables are defined in Table 1. t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6
Endogeneity: Two-Step System GMM.

	(1)	(2)	(3)
VARIABLES	SEP	SEP	SEP
Private foreign investment & aid	65.708**		
	(2.482)		
Private foreign investment		103.982***	
		(2.675)	
Private foreign aid			37.070
			(0.942)
Lagged_SEP	−0.100*	−0.366**	0.009
	(−1.703)	(−2.251)	(0.067)
GDP per capita	5.796	6.453	11.809
	(0.963)	(1.207)	(1.389)
GDP growth	−0.240	−0.069	0.069
	(−1.161)	(−0.303)	(0.351)
Trade openness	0.003	0.007	0.109
	(0.035)	(0.090)	(0.892)
Foreign direct investment	−0.428	−0.568	−0.289
	(−1.031)	(−1.479)	(−0.413)
Carbon emission	6.896	10.251	−2.487
	(0.801)	(1.338)	(−0.289)
Energy consumption	−41.377**	−51.296***	−22.406**
	(−2.354)	(−2.885)	(−2.222)
Constant	116.609**	143.741***	9.958
	(2.368)	(2.815)	(0.146)
Arellano-Bond test for autocorrelation	0.390	0.251	0.581
Hansen test for valid instruments	0.826	0.340	0.432
Observations	1943	1426	492

Notes: This table presents the results of the Two-Step System Generalised Method of Movements (SGMM) using the three sources of investment and aid as independent variables. The post-estimation tests, including the Arellano-Bond test of autocorrelation and the Hansen test for valid instruments, are also presented. All the variables are defined in Table 1. t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

energy production is fundamentally shaped by the quality of governance in recipient countries, with corruption playing an increasingly complex and constraining role (Alesina and Weder, 2002). Despite significant technological advancements and expanding financial resources, the success of renewable energy projects remains critically dependent on institutional frameworks that ensure accountability, transparency, and efficiency. Past studies have established different relationships between corruption and foreign aid and investment (Bauhr et al., 2013; Krasniqi and Demukaj, 2021; Tavares, 2003; Yu et al., 2022). For instance, Amin et al. (2021), based on a panel analysis of 68 developing countries, found that private energy investments only reach their intended capacity targets when key sectoral reforms are in place. A recent study by Yu et al. (2022) suggest that corruption negatively impacts foreign aid effectiveness in many developing countries. Bauhr et al. (2013) also argue that corruption in recipient countries causes aid fatigue to the donor countries. This empirical evidence suggest that the effectiveness of private foreign aid and investment is likely to be dependent on the level of perceived corruption in the recipient country. Studies examining corruption's role in energy production across developing nations (Eberhard et al., 2017; Sovacool et al., 2014) reveal that corruption no longer operates solely through outright misappropriation but has shifted towards more subtle mechanisms, including policy manipulation, regulatory capture and preferential contracting. Therefore, we conduct further analysis to examine whether the level of perceived corruption in the recipient country could influence the relationship between private foreign investment & aid and sustainable energy production. Consistent with prior studies (Tawiah et al., 2024), we use the Bayesian corruption index as the measure of corruption. We use a sub-sampling approach to classify the countries into high and low corrupted countries based on the sample median.

The results are presented in Table 7. The results of low-corrupt countries are presented in columns 1 to 3, while high-corrupt

Table 7
The impact of corruption.

	Low corruption			High corruption		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	SEP	SEP	SEP	SEP	SEP	SEP
Private foreign investment & aid	70.536***			56.142***		
	(4.049)			(4.951)		
Private foreign investment		58.502***			42.303***	
		(3.017)			(3.122)	
Private foreign aid			−11.298			−3.337
			(−0.551)			(−0.099)
GDP per capita	7.550***	8.500***	11.045**	3.229*	2.642	14.664***
	(2.668)	(2.637)	(2.364)	(1.904)	(1.360)	(2.791)
GDP growth	−0.389	−0.246	−0.051	0.024	0.123	0.842
	(−1.425)	(−0.782)	(−0.106)	(0.119)	(0.500)	(1.287)
Trade openness	0.039	0.014	−0.089	−0.027	−0.051	0.130*
	(0.782)	(0.248)	(−1.040)	(−0.985)	(−1.563)	(1.847)
Foreign direct investment	0.290	0.186	1.061***	−0.926***	−0.459	0.906
	(1.118)	(0.646)	(3.177)	(−3.215)	(−1.310)	(0.785)
Carbon emission	−14.466***	−13.269***	−16.218***	−8.995***	−8.571***	−10.361**
	(−6.446)	(−5.150)	(−4.204)	(−6.182)	(−4.986)	(−2.313)
Energy consumption	2.906***	2.886***	2.044	−2.854**	−2.037	−9.090*
	(3.433)	(2.898)	(1.562)	(−2.449)	(−1.429)	(−1.776)
Constant	−35.641	−35.312	−51.817	19.218	21.286	−75.633
	(−1.616)	(−1.385)	(−1.319)	(1.410)	(1.339)	(−1.363)
Year effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	735	532	302	1269	926	191
R-squared	0.110	0.098	0.129	0.129	0.116	0.152

Notes: This table presents the effect of corruption on the relationship between private foreign investment & aid and sustainable energy production (SEP). The results of low-corrupt countries are presented in columns 1 to 3, while high-corrupt countries are in columns 4 to 6. All the variables are defined in Table 1. t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

countries are in columns 4 to 6. Private foreign investment & aid have a stronger and more significant impact in low-corruption countries compared to high-corruption economies. The coefficient for private foreign investment & aid is 70.536 ($p < 0.01$) in low-corruption settings, significantly higher than 56.142 ($p < 0.01$) in high-corruption contexts. This suggests that transparent regulatory frameworks and stronger governance quality enhance the effectiveness of private financial flows in driving sustainable energy production. Research has shown that corruption distorts investment efficiency, leading to misallocation of resources and reduced economic productivity (Wang et al., 2020). In contrast, low-corruption economies provide a more predictable business environment, allowing private investors to allocate funds effectively towards high-impact energy projects. We find similar results for private foreign investment alone (difference of 16.199; t-statistics 3.73****), suggesting that investment is more effective when corruption levels are lower. Meanwhile, the positive and significant but small coefficient in highly corrupt countries suggests that corruption erodes but doesn't eliminate the benefits of private foreign investment. Private foreign aid, however, exhibit a negative but insignificant effect in both corruption contexts (−11.298 in low corruption and − 3.337 in high corruption). This suggests that philanthropic aid alone may not substantially contribute to sustainable energy production, possibly due to inefficiencies in aid allocation, lack of structured investment mechanisms or mismanagement (Kim, 2019). This finding indicates that despite private aid's unique advantages, such as targeted investment, professional oversight, and efficiency in fund management, its success is contingent on the institutional environment in recipient countries (Kosack and Tobin, 2006). Corruption as a social cancer hampers the implementation and monitoring of sustainable energy production projects. For instance, while private aid donations (e.g. Gates or Bezos Foundations) are typically assigned to specific projects with clear sustainability goals, corruption can hinder their effectiveness. In highly corrupt environments, project administrators and officials may divert funds for personal gain, leading to suboptimal implementation, inferior materials usage and weakened oversight. The findings are consistent with prior studies (Bauhr et al., 2013; Yu et al., 2022) that highlight corruption as a systemic barrier to effective aid deployment.

5.5. The effect of financial crisis

Private foreign investment and aid hold distinctive advantages in fostering sustainable energy development, particularly due to its independence from political and diplomatic motives, targeted funding approach and professional management efficiency (Falcone, 2023). However, financial crises could weak the relationship between private investment & aid and energy production by reducing liquidity, increasing risk aversion, and redirecting capital towards short-term, lower-risk priorities (Burger et al., 2009). During financial downturns, constrained access to capital hinders the funding of energy transition projects, which are often capital-intensive and require long-term commitment (Mazzucato and Semieniuk, 2018). Additionally, private investors often prioritize investments with immediate returns, sidelining long-term renewable energy projects that require substantial initial capital and extended payback periods during crises (Polzin, 2017). Furthermore, credit constraints and elevated financing costs exacerbate the challenges for renewable energy investment, which is already sensitive to economic uncertainty (Zhang et al., 2016). This disruption is particularly pronounced in developing countries, where reliance on private foreign capital for energy transition is high, making the sector vulnerable to economic instability and slowing progress towards sustainability goals.

Table 8 examines how financial crises influence the relationship between private investment and aid, and energy production in developing countries. We code 2008–2010 as the global financial crisis period. While private investment and aid exhibit a positive and significant impact on energy production as shown in column (1), financial crises substantially weaken this relationship. The interaction terms in Columns (1) and (2) reveal a negative and significant effect across both investment and investment + aid, demonstrating that financial crises significantly disrupt the effectiveness of private financial flows in

Table 8
The effect of financial crises.

	(1)	(2)	(3)
VARIABLES	SEP	SEP	SEP
Private foreign investment & aid	9.770**		
	(2.361)		
Private foreign (investment&aid) * Crisis	−23.262***		
	(−3.120)		
Private foreign investment		14.263***	
		(2.908)	
Private foreign investment*Crisis		−28.126***	
		(−3.438)	
Private foreign aid			3.401
			(0.405)
Private foreign aid*Crisis			4.306
			(0.494)
Crisis	3.291	7.558**	44.698***
	(1.362)	(2.572)	(3.981)
GDP per capita	−2.008*	−1.493	0.035
	(−1.888)	(−1.228)	(0.010)
GDP growth	−0.150***	−0.037	0.166
	(−2.914)	(−0.584)	(1.615)
Trade openness	0.049***	0.045**	0.007
	(2.938)	(2.296)	(0.138)
Foreign direct investment	0.103	0.042	−0.090
	(1.574)	(0.565)	(−0.917)
Carbon emission	−5.528***	−4.543***	−13.612***
	(−4.729)	(−3.339)	(−4.206)
Energy consumption	−3.200***	−3.395***	10.195***
	(−7.099)	(−6.817)	(4.629)
Constant	130.400***	125.106***	−6.017
	(15.860)	(13.473)	(−0.187)
Country effect	Yes	Yes	Yes
Year effect	Yes	Yes	Yes
Observations	2004	1458	493
R-squared	0.926	0.930	0.968

Notes: This table presents the moderating impact of financial crises on the relationship between private investment & aid and sustainable energy production. Year 2008 to 2010 is coded as financial crises. All the variables are defined in Table 1. t-statistics in parentheses, *** p < 0.01, ** p < 0.05, * p < 0.1.

supporting energy transitions. This is mainly due to heightened risk aversion, reduced liquidity, and redirected investment priorities (Geels, 2013). This indicates that while private investment and aid aim to mitigate climate change through energy investments, economic instability may redirect their priorities towards stabilizing business operations, temporarily stalling their sustainability-focused commitments. Additionally, the negative coefficients of the interaction terms further highlight how financial crises exacerbate existing structural challenges in the energy sector of developing countries. By undermining the effectiveness of private investment and aid, financial crises stall progress in energy transition, as evidenced in past global and regional economic disruptions (Aklin and Urpelainen, 2018). Developing economies, already reliant on private capital to bridge energy funding gaps, face compounded risks during crises, which hinder their ability to pursue sustainable energy goals. This aligns with research suggesting that crises often lead to prioritisation of immediate returns, often at the expense of long-term renewable energy projects (Taghizadeh-Hesary and Yoshino, 2019). Unlike investment, private foreign aid (Column 3) does not exhibit a strong moderating effect during crises. The interaction term for aid during crises is statistically insignificant, indicating that philanthropic aid continues to flow and remains relatively unaffected by financial shocks. This suggests that while investment contracts sharply during crises, aid maintains its presence but lacks the transformative power of investment.

5.6. Continental analysis

The literature on the effect of foreign aid on economic growth and development has produced mixed findings. Some scholars argue that some countries in Asia and Europe have effectively used foreign aid and have transitioned from aid recipients to aid donors (Maruta et al., 2020; Sandersley, 1987). For instance, Maruta et al. (2020) report that while education aid is more effective in South America, health aid is more effective in Asia, and agricultural aid is more effective in Africa. These contrasting findings and arguments suggest that there could be continent differences in the outcome of foreign aid and investment. Therefore, in this section, we examine whether the continent location of countries could impact the relationship between private investment & aid and sustainable energy production in developing countries. To do this, we group the countries into four main continents, namely: Africa, America, Asia and Europe. The grouping of the countries is based on their respective geographical locations.

The results of the continent analysis are presented in Table 9. The coefficient of private foreign investment & aid is positive and significant in all the columns except for Asia in column 3. However, we observe a significant difference in the size of the coefficient across the continent. The coefficient of Africa is larger than the remaining three. This is followed by the Americas and Europe. The results suggest that while private foreign investment & aid have a significant impact on sustainable energy production across the continents, the result is more pronounced in Africa and the America. We perform multi-level/nested regression to aggregate data from all continents to provide a comprehensive and multi-level analysis. This approach helps identify overarching trends while controlling for regional differences. The nested results are presented in Column 5. The coefficient for private investment and aid remains positive and significant ($\beta = 70.679$, significant at the 1 % level), reinforcing its role as a key driver of energy transition across developing economies. The results align with Maruta et al. (2020), who report the differential impact of foreign aid across the continents, emphasizing the varying effectiveness of financial flows in shaping sustainable energy development globally.

5.7. The effect of human development index (HDI)

To further demonstrate the underlying channels and influential factors across countries, we examine the effect of human development index (HDI) on the relationship between private foreign investment & aid and sustainable energy production. We adopt a sub-sampling approach to group countries into high, medium and low HDI as defined by UNDP. The results presented in Table 10 indicate that while the coefficient of Private investment & aid is positive and highly significant across all classifications, there are notable differences between the groups. To further identify overarching trends while controlling for regional differences, we conducted the multilevel/nested regression, which shows private investment & aid remain positive and significant ($\beta = 52.793$, significant at the 1 % level), confirming its overall role in driving energy transitions across HDI groups. Additionally, the likelihood ratio LR test ($\chi^2 = 180.99$, $p < 0.001$) confirms that the multilevel structure is necessary to explain the variations in the sample.

6. Conclusion

Private foreign investment and aid play a crucial role in addressing climate change issues globally. Wealthy individuals and corporations have consistently provided substantial aid to support various sustainable living initiatives, with sustainable energy being a top priority among them. Empirical evidence and trends of foreign investment and aid to developing countries indicate that these funds are less likely to achieve their target goals in terms of efficiency and effectiveness. Existing literature provides evidence that foreign investment and aid is ineffective in developing countries (Doucouliagos and Paldam, 2009; Hansen and Tarp, 2000; Tawiah et al., 2018; Tawiah and Karungi, 2020). However, previous studies did not consider the uniqueness of private foreign investment and aid. Furthermore, the past studies focused on the

Table 9
Continental analysis.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Africa	America	Asia	Europe	Nested
Private investment & aid	109.875***	104.620***	−22.882	64.745**	70.679***
	(7.526)	(6.092)	(−1.647)	(2.418)	(8.266)
GDP per capita	−14.829***	15.163***	−7.771***	−22.355***	−0.702
	(−5.679)	(5.285)	(−2.942)	(−3.499)	(−0.574)
GDP growth	−0.142	0.660*	0.670**	0.341	0.042
	(−0.667)	(1.915)	(2.401)	(0.899)	(0.284)
Trade openness	0.246***	−0.231***	0.083**	0.380***	−0.002
	(6.131)	(−5.610)	(2.299)	(3.694)	(−0.086)
Foreign direct investment	−0.389	−1.011***	−1.139***	0.733	−0.456***
	(−1.558)	(−2.765)	(−3.588)	(1.214)	(−2.598)
Carbon emission	−3.715*	−24.377***	−10.699***	−10.266**	−11.710***
	(−1.845)	(−8.861)	(−6.127)	(−2.090)	(−10.995)
Energy consumption	−1.925**	17.103***	0.582	11.956***	−0.431
	(−2.336)	(6.074)	(0.334)	(7.256)	(−0.657)
Constant	113.307***	−107.559***	76.767***	135.509***	40.901***
	(5.572)	(−4.890)	(4.101)	(3.826)	(3.014)
Year effect	Yes	Yes	Yes	Yes	Yes
Observations	969	457	503	75	2004
R-squared	0.212	0.461	0.357	0.921	

Notes: This table presents the impact of private foreign investment and aid on energy transitions based on geographical location of the sample countries. Sample countries are grouped based on 4 continental classifications: Africa, Americas, Asia and Europe. All the variables are defined in Table 1. t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 10
The effect of Human Development Index (HDI).

	(1)	(2)	(3)	(4)
VARIABLES	High HDI	Medium HDI	Low HDI	Nested
Private investment & aid	90.455***	39.796***	90.413***	52.793***
	(7.562)	(3.451)	(3.092)	(6.109)
GDP per capita	12.558***	−3.044	−5.340	0.462
	(8.005)	(−1.556)	(−0.755)	(0.392)
GDP growth	−0.667***	−0.297	−0.050	−0.259*
	(−2.931)	(−1.473)	(−0.132)	(−1.744)
Trade openness	−0.212***	0.160***	−0.171*	−0.033
	(−9.830)	(4.555)	(−1.927)	(−1.478)
Foreign direct investment	1.176***	−1.478***	0.910**	−0.084
	(4.741)	(−5.640)	(2.259)	(−0.470)
Carbon emission	−43.824***	−8.639***	−17.527***	−15.308***
	(−25.831)	(−5.581)	(−3.731)	(−13.919)
Energy consumption	4.780***	−12.271***	1.310	−2.379***
	(5.433)	(−9.231)	(1.121)	(−3.510)
Constant	−51.757***	84.010***	15.302	43.397**
	(−3.664)	(5.344)	(0.297)	(2.290)
Year effect	Yes	Yes	Yes	
Observations	553	1093	358	2004
R-squared	0.659	0.221	0.214	

Notes: This table presents the impact of human development index (HDI) on the relationship between private foreign investment & aid and sustainable energy production. Sample countries are grouped into three categories: High HDI, Medium HDI and Low HDI. The dependent variable is measured as ratio of private foreign investment and aid to GDP. Independent variable is measured as renewable electricity output as percentage of total energy production. All other variables are defined in Table 1. t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

overall economy without attention to specific sectors such as energy. Arguably, private foreign aid and investment are unique and mostly target specific sectors. Hence, its effectiveness in affecting sustainable energy production could be different from that of generic aid from donor countries. Therefore, in this paper, we have examined the impact of private foreign investment and aid to the energy sector on sustainable energy production in developing countries.

We employ a robust econometric identification strategy on a large sample from 102 developing countries between 1990 and 2021. Our econometric identification strategy includes Pool Group Mean regression estimation and Two-Step System Generalised Method of Moments (GMM). Our results demonstrate a positive and statistically significant effect of private foreign investment and aid on sustainable energy production, with the impact being more pronounced for private investment. Countries with higher levels of private financial inflows tend to experience more substantial progress in renewable energy generation. Recognizing the role of institutional quality, we investigate whether corruption alters this relationship. The analysis reveals that corruption significantly weakens the positive influence of both private investment and aid, reducing their effectiveness in promoting sustainable energy in more corrupt developing countries relative to their less corrupt counterparts. Given the diverse location of the sample countries, we further investigated whether the impact of private investment and aid on sustainable energy utility production differs across continents. We find the benefit of private investment and aid to the energy sector in developing countries is more pronounced in African areas, while Asia is the least beneficiary in terms of harnessing the benefit from private investment in the energy sector. Our results are robust to alternative measurements and different econometric models for addressing endogeneity issues.

The findings underscore the need for tailored, region-specific policy interventions to maximize private foreign aid's impact on energy transitions, moving beyond broad prescriptions to address contextual institutional and market barriers. In Africa, where grid infrastructure gaps and financing constraints persist, governments should prioritize structured public-private partnerships (PPPs) with clear risk-sharing mechanisms, modelled after successful initiatives like South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), which attracted $14 billion in private investment by guaranteeing grid access and dollar-indexed tariffs (Eberhard and Naude, 2016). Such partnerships must be coupled with local capacity-building mandates, a lesson from Kenya's Lake Turkana Wind Power project, where weak local maintenance capabilities initially undermined operational efficiency (Rotich et al., 2024). For Latin America, the priority lies in streamlining regulatory frameworks to reduce bureaucratic delays, drawing on Chile's success in cutting renewable project approval times, while introducing stability clauses to prevent retroactive policy changes that deter investors, a challenge observed in Brazil's solar sector (Costa et al., 2022). In Asia, policymakers should combine tax incentives with supply-chain localization requirements, following Vietnam's solar

boom driven by 5-year corporate tax holidays and domestic manufacturing quotas (World Bank, 2025), though with safeguards against the oversupply crises.

Despite the robustness checks, this study is not without limitations. While the use of system GMM estimator within the Arellano–Bond framework offers advantages for addressing endogeneity in dynamic panels, its reliance on internal instruments raises concerns. Although the relatively long time series in our dataset helps mitigate weak instrument problems (Bun and Windmeijer, 2010), it may also weaken the Hansen test, making it prone to Type II errors by over-accepting the null of instrument validity. In the absence of external valid instruments, our results should therefore be interpreted with caution. Future studies could complement this approach by employing external instruments or alternative identification strategies to reinforce the robustness of causal claims. We were also limited in our ability to identify the specific country sources of private aid. Future studies could explore how the origin of private investment and aid to the energy sector could affect its effectiveness. Moreover, most private aid and investment do not occur in isolation and they are mostly associated with large multinational companies. Hence, the amount of foreign direct investment and the number of MNCs from the source country could influence private aid and investment in the production of sustainable energy and supplies. Another promising avenue for future research lies in extending the analysis from the country-level to the firm and project-level, where the dynamics of private investment and aid in driving energy transition can be more directly examined. For instance, firm-level studies would allow researchers to capture heterogeneity in managerial decisions, governance structures, and technological adoption that aggregate country-level data may obscure. Similarly, project-level analyses could provide insights into implementation efficiency, financing mechanisms, and performance outcomes of specific renewable energy initiatives, offering practical lessons for scaling up private participation in sustainable energy. Such micro-level perspectives would complement the macro-level findings of this study and deepen understanding of the mechanisms through which private foreign investment and aid contribute to energy transition in developing contexts.

CRediT authorship contribution statement

Vincent Tawiah: Formal analysis, Data curation, Conceptualization. **Abdulrasheed Zakari:** Methodology, Investigation, Formal analysis. **Yan Wang:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Francis Osei-Tutu:** Writing – review & editing, Writing – original draft.

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