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Research article

Risk allocation schemes between public and private sectors in green energy projects

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A R T I C L E I N F O

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A B S T R A C T

In this research, we analyse how project risk allocation strategies impact the volume of private investment in renewable energy projects with the participation of both the public and private sectors. To this purpose, we analyse a sample formed by 2215 projects performed in 73 developing countries in the period 1997–2019 involving the following technologies: solar, hydro, wind, waste, biogas, biomass, and geothermal. Our findings reveal that those projects performed through governance schemes in which the private partner takes more project responsibilities attract more private money. Additional drivers for attracting private investment at the project level and institutional level are found. Furthermore, we reveal that the transference of project risks to the private partner emerges as a very relevant project feature that interacts with some of the project and institutional factors, revealing both complementary and substitution effects. The significance of this research extends beyond academia, since there are factors influencing private investment that can be controlled by various stakeholders in projects (such as policymakers, private investors, and project managers). Understanding their impact, significance, and interaction effects—factors that sometimes moderate or accentuate private investment—is crucial. The identified patterns illuminate optimal risk allocation practices, offering practical insights to enhance the effectiveness and sustainability of projects.

1. Introduction

Fossil fuel burning and the consequent concentration of greenhouse gases in the atmosphere is one of the main sources of global warming. The consequences of global warming encompass a set of environmental phenomena with a high impact on ecosystems and people including, among others, reduced agricultural productivity, forest degradation, biodiversity loss, species shift, sea level rise, and increased occurrence of cyclones, floods, and heatwaves (Mariappan et al., 2023). All of these phenomena impact developing countries more severely. Mertz et al. (2009) explain that climate change is more challenging for developing countries since i) these countries are mainly located in low-latitude regions already characterized by high temperatures, and new rises in temperatures will lead to large evaporation losses; ii) economy and employment in developing countries could be especially impacted by climate change since many people in these countries depend on the agriculture sector, which is especially sensitive to the consequences of global warming; iii) poor people, more prevalent in these countries, are more vulnerable to the negative consequences of climate change (Yohe and Tol, 2002); and iv) these countries suffer from more limitations at the economic and technological levels when it comes to facing the challenges arising from global warming.

Renewable energies emerge as a very useful tool to put the brake on global warming, fostering the transition to a low-carbon economy (Martí-Ballester, 2019; Fleta-Asín and Muñoz, 2021; Piterou and Coles, 2021). The promotion of renewable energies in developing countries is explicitly included in the Sustainable Development Goals (SDG) of the United Nations (UN). The seventh SDG sets out the need to “ensure access to affordable, reliable, sustainable and modern energy”; more concretely, target 7b points out the requirement, by 2030, to “expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support”. Cheng et al. (2021) conclude that improvements in energy productivity, renewable energy, and technological innovation negatively impact CO_2 emissions. Zoaka et al. (2022) demonstrate a positive relationship between the utilization of renewable energy and

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the environmental quality in the BRICS nations. In essence, the study provides evidence supporting the idea that increased reliance on renewable energy sources has a beneficial impact on the environment in these specific countries. Abbasi et al. (2022) explore various aspects of renewable energy consumption, such as its relationship with carbon dioxide emissions, economic growth, and other relevant factors, concluding that renewable energy consumption is a key factor for achieving sustainable environmental goals.

Public-private partnerships (PPPs) can constitute a very useful formula in the promotion of renewable energies in developing countries (Khan et al., 2020). This transaction governance mechanism involves the cooperation of public authorities and private companies in the building and operation of facilities in different sectors, including energy. Thus, "partnerships pool complimentary capacities, resources and assets from different players and create synergies. Ultimately, they provide a solution that is not facilitated by a single actor" (Eitan et al., 2019, p. 96). Given the scarcity of economic and technological resources among governments in developing countries, the attraction of private investment could be crucial to promote the renewable energy solution in those locations (Chauhan and Marisetty, 2019).

Rajpurkar (2015) explains that private participation in renewable energy projects through PPPs can contribute to reduce costs and enhance technological efficiency. Consequently, PPPs have gained prominence as a policy response to climate change, fostering collaborations between governments and private entities (Buso and Stenger, 2018). The support extended by the multilateral development banks (MDB) to renewable energy projects in developing countries has been a significant aspect of these partnerships (Basílio, 2023).

The impact of PPP investment in energy and technological innovation on the ecological footprint has been explored in various contexts, such as the case of Pakistan (Chunling et al., 2021).

In the realm of renewable energy access and consumption, the influence of PPPs on consumption-based carbon dioxide emissions in India has been investigated, offering insights into the intricate relationship between public-private collaborations and environmental outcomes (Kirikkaleli and Adebayo, 2021). Additionally, the exploration of PPPs in agro-energy districts in Southern Europe, as evidenced by cases in Greece and Italy, has provided valuable lessons for sustainable energy initiatives (Manos et al., 2014).

The Portuguese experience in wind power generation through PPPs has been examined, shedding light on the dynamics and challenges faced in such collaborations (Martins et al., 2011). Furthermore, the role of technological innovations in China's PPP investment in energy has been identified as a determinant of CO2 emissions (Shahbaz et al., 2020). In addressing renewable energy access in the developing world, Sovacool (2013) emphasizes the potential of pro-poor PPPs to expand access and promote sustainability.

Recently, in a sample of 1371 PPPs involving renewable energies, Fleta-Asín and Muñoz (2021) analysed what determines the percentage of the project company that is owned by private sponsors. The authors found that the percentage of the project company owned by private sponsors is larger in projects that are smaller, younger, and governed by PPPs in which more risks are transferred to the private partner, supported by MDBs, and performed in sounder economic and institutional frameworks.

In this research, we want to shed light on PPPs in renewable energies literature by analysing the factors that determine the volume of private investment in these projects, and we are especially interested in the effect of the risk allocation strategies. Both aspects—drawing private investment and implementing risk allocation strategies—are key benefits of PPPs. Thus, the successful implementation and development of PPPs will depend on the ability to attract appropriate private-sector investments (Osei-Kyei and Chan, 2017). Traditionally, PPPs have been identified as a very useful tool for public authorities to mitigate the national budget deficit and ensure the procurement of infrastructure and services (Bing et al., 2005; Chou et al., 2015). More recently, risk allocation has been identified in specialized academic literature as the main provider of efficiency in the governance of projects through PPPs (Bing et al., 2005; Hodge and Greve, 2007; Fleta-Asín and Muñoz, 2020).

In addition, in this study, we broaden the conventional scope of PPPs to encompass management and lease contracts, recognizing the diverse array of collaborative models that contribute to the spectrum of public-private engagements. Despite the typically shorter durations (three to five years) and absence of ownership transfers associated with management and lease contracts, we extend their classification within the broader PPP framework. This inclusive approach aligns with evolving perspectives in the field, acknowledging that private sector involvement in public projects manifests in various forms. Notably, we order management and lease contracts alongside other PPP categories based on the degree of risk transferred to the private operator, contributing to a comprehensive understanding of the risk landscape within the spectrum of collaborative initiatives. Leveraging insights from the World Bank's PPP contract types and terminology guide, our study aims to provide a nuanced exploration of the multifaceted nature of public-private collaborations in infrastructure and services provision.

Thus, the main objective of the work is to analyse how the risk transferred to the private operator through the contract affects the attraction of the private investment volume (H1). This is done by including specific characteristics of the project (H2–H6) and environment variables (H7–H9). Subsequently, Hypothesis 10 analyses how the effect of risk (H1) interacts with the other project and environment hypotheses (H2–H9) that have previously been analysed individually. For this purpose, we analyse a broad sample of PPPs on renewable energies formed by 2215 projects performed in the period 1997–2019 in 73 developing countries and encompassing the following technologies: solar, hydro, wind, waste, biogas, biomass, and geothermal.

The rest of the paper is structured as follows. Section 2 establishes the literature review and research hypotheses; section 3 describes the data and methods used; section 4 reports the main empirical findings and discusses them; and section 5 ends the research with the main conclusions.

2. Literature review and research hypotheses

2.1. Impact of risk allocation strategies on private investment

Uncertainty surrounding transactions involved in PPP projects makes the risk allocation between the partners a very relevant feature. These risk factors arise from different sources (Fleta-Asín et al., 2020). Academic literature has identified risk factors emerging from the bounded rationality of the agents and the incompleteness of contracts (Iossa and Martimort, 2016); from the external environment, such as the occurrence of economic, environmental, or social events impacting PPPs' functioning (Abdi and Aulakh, 2012; Niknazar and Bourgault, 2017); and from the opportunistic behaviour of the agents involved in the transactions (Williamson, 1979; Jin and Doloi, 2008). Bing et al. (2005) explain that the risks involved in PPPs can be classify into three broad categories: macro, meso, and micro levels. The first includes issues related to the environment where the collaboration occurs, such as political, macroeconomic, legal, social, or natural risks. The second encompasses risk events occurring within the boundaries of the project, related to finance, design, construction, and operational responsibilities. The third refers to behavioural risks arising mainly in the partners (both the public and the private) performing the project, but also in other stakeholders. Bing et al. (2005) conclude from a questionnaire survey distributed among people with experience in PPP management that whereas macro and micro risks should be mostly managed by the public sector or shared for both partners, meso risks should be mostly transferred to the private contractor since it will be more efficient in managing them. Similar empirical evidence is provided by Ke et al. (2010) and Hwang et al. (2013), among others.

PPPs do not follow a homogeneous project governance formula, and the amount of risk transferred from the public to the private sector materializes in the specific type of PPP promoted. In this regard, the World Bank classifies PPPs into different types (contractual forms) according to the risks taken by the private partner.[1] More concretely, these categories reflect a different degree of transference of the risks emerging from the project (meso risks). From less to more risk transferred to the private partner, first we find management and lease contracts in which a private company assumes the management of a public asset for a fixed period but the public authority retains the ownership and investment decisions. Secondly, in brownfield projects, a private company assumes control of an existing asset, fixes it, and rehabilitates or expands its capabilities. The same private partner operates the asset for a period and the asset may subsequently return to the public sector. Thirdly, in greenfield projects are a private company or a public-private joint venture that builds and operates a new facility for the period specified in the contract. The private partner takes on many of the financial and operational risks. Each of these categories is, in turn, divided into other subtypes, again ordered from less to more risk taken by the private sector. Thus, within the first category, we find management contracts and lease contracts. Brownfield projects are divided into "rehabilitate, operate and transfer", "rehabilitate, lease or rent, and transfer", and "build, rehabilitate, operate and transfer". The greenfield projects are divided into "build, lease, and transfer", "build, operate, and transfer", "build, own, and operate", "merchant" and "rental".[2] These contractual categories of PPP differ in the allocation of the residual control rights over the assets involved in the transaction. The party in the transaction holding a higher degree of residual control rights and ownership takes more risk. In this way, in PPP schemes in which more risks are transferred outside the public sphere, the private contractor will enjoy more residual control rights over the assets (Wang et al., 2019a).

Risk allocation strategies constitute one of the more analysed topics in the PPP literature. Broadbent and Laughlin (1999) highlight that one of the primary concerns for the public sector is determining the extent of risk transferred to the private sector, as effective risk management is a key factor in achieving value for money (VfM). We can find a plethora of articles that have aimed to identify the main risk factors in PPPs and what should be the optimal allocation between the public and private sectors (see, among many others, Grimsey and Lewis, 2002; Abednego and Ogunlana, 2006; Ke et al., 2010; Hwang et al., 2013; Nguyen et al., 2018; Wang et al., 2019a). Recently, academic literature has provided empirical evidence supporting that more risks related to the project (meso risks) transferred to the private partner impact positively on different projects' dimensions. Thus, Fleta-Asín and Muñoz (2020) find that PPP types in which the private partner assumes more responsibilities perform better. Fleta-Asín and Muñoz (2021) find that PPP types in which the private partner takes on more risks are positively related to the percentage of the project company owned by private sponsors.

The public partner might prefer PPP types in which the private partner assumes most of the project risks for several reasons. Firstly, bundling responsibilities in the private partner is a mechanism to alleviate moral hazard problems (Owusu-Manu et al., 2021) mitigating micro risks related to opportunistic behaviours of the private contractor. In this regard, where the same private contractor takes on the responsibility of building and operating the facility, the incentive of the private party to underinvest during the building phase of the asset diminishes, since this can hinder their outcomes during the exploitation phase (Nisar, 2007). Secondly, the promotion of PPP formulas in which the public party transfers more project risks could be useful to alleviate the adverse selection problem. Ex-ante, in the tendering process, it caters to potential private partners that are able to manage these risks (Jin and Doloi, 2008; Fleta-Asín et al., 2020). Ex-dure, once the project has been awarded, the private acceptance of risks will provide greater efficiency in the project execution since the cost-benefit analysis made for the private partner before making its decision to engage in the PPP would forecast positive outcomes (Effah Ameyaw and Chan, 2013; Jin and Zhang, 2011). In this regard, the prospect theory explaining the decision-making process under risk predicts that private companies will estimate the potential gains and losses before deciding to engage in a PPP project, and only in the case of gains outweighing losses will the private partner invest in the project (Kahneman and Tversky, 1979; Wang et al., 2019a). Besides, the private partner also has reasons to prefer engaging in PPPs in which it takes on more of the project's risks. That is to say, bundling responsibilities in private partners leads to a temporary allocation of property rights to the private contractor, which could enlarge the scope for efficiency gains (Grossman and Hart, 1986; Hart et al., 1997; Hart, 2003). The private contractor will have more incentives to perform efficiently since controlling rights over a project's assets will allow it to operate the asset for a longer period and under more favourable conditions (Wang et al., 2018a). PPPs in which the public sector retains more tasks constrain the scope of activities in which the private companies can participate. Conversely, projects in which the private sector takes on more responsibilities could be more attractive for private money due to the greater possibilities for business.

In this way, the type (subtype) of PPP promoted by the government reflects the strategic decision as to the extent of the project risks transferred to the private partner, and the above reasoning leads us to propose our first research hypothesis.

H1. PPPs in which the private partner assumes more project risks attract more private investment.

2.2. Impact of other projects' characteristics on private investment

Firstly, we consider that other project characteristics can significantly impact the volume of private investment in renewable energy PPPs. Thus, we consider the contract award method. Public partners can opt for a competitive method (competitive bidding) or a non-competitive method (direct negotiation). The optimal method to select the private partner will depend on the project's features (Kaminsky, 2017). Competitive bidding is the optimal method when the public partner wishes to make the tendering process transparent. The principal-agent relationship can be better established through a competitive awarding method since this allows selection of the optimal private partner (Wang et al., 2018a) by fostering competence ex-ante. However, from a principal-stewardship lens of analysis, direct negotiation has some advantages. Some of these positive aspects are: i) savings in time and cost in the tendering process; ii) flexibility in facing changing conditions; iii) reduced adversarial relationships between the partners; and iv) broadening the scope of activities in which the private investor can be involved (Gordon, 1994; Zawawi et al., 2016). Direct negotiation methods allow relationships based on trust (Davis et al., 1997; Wang et al., 2018a), which makes it easier to face unforeseen events during contract enforcement. Competitive bidding is optimal when the public sector wants to select a private partner that will carry out the project at the lowest cost (Kaminsky, 2017). Thus, under competitive awarding methods, expectations of future excess profits for private companies can be significantly reduced (Cunha-Marques and Berg, 2011). This gives rise to incentives for the private partner selected to underinvest or jeopardize the service quality during contract execution or promote the lack of interest of private contractors to join the bid competition (Soomro and Zhang, 2016).

[1] The World Bank includes a fourth category, divestitures, that are related to the privatization processes of state-owned companies. Following previous literature, we do not consider divestitures in our research since these formulas do not suppose cooperation between the public and private sectors (see among others, Cruz and Marques, 2011; Wang et al., 2019a; Zhao and Ying, 2019).

[2] A detailed definition of each category and the risks assumed by the private investors can be found on the World Bank website: https://ppi.worldbank.org/en/methodology/glossary.

Thus, we propose the following research hypothesis.

H2. Direct negotiation methods attract more private investment.

In addition, the projects in our sample are performed in developing countries. In these countries, it is very common that the private contractor in infrastructure PPPs is a huge foreign multinational (or a pool of foreign companies) with the resources (both human and financial), technology, and experience to tackle the project. Thus, these companies suffer from liability of foreignness (Dykes et al., 2020). Private contractors have to operate in unfamiliar economic and institutional environments, this posing a challenge for the project performance. In this way, the involvement of a local sponsor in the project could alleviate the uncertainties faced by private contractors as a result of liability of foreignness. We can find in the PPP academic literature several works that have considered local sponsor participation as a key driver of value for money. In this regard, Fleta-Asín and Muñoz (2020) find that the presence of a local partner is positively related to the PPP's performance. Jiménez et al. (2017) find similar results and justify that "higher familiarity with the host-country idiosyncrasy reduces the liability of foreignness limitations suffered by the rest of the firms in the project" (p. 788). On the same lines, Dulaimi et al. (2010) point out that local partners allow foreign private investors to access local knowledge and business networks.

Thus, our third research hypothesis is.

H3. The participation of a local partner in the project positively relates to the volume of private investment.

Another relevant project characteristic that might impact the attraction of private investment is the existence of government support programmes backing the operation. Wang et al. (2019b) explain that host country governments often perform a set of direct and indirect support policies to encourage and attract private investment to PPPs. These authors therefore differentiate between direct and indirect government support programmes. Direct government support programmes include capital subsidies (cash grants to support the costs of assets during the building phase), revenue subsidies (grants to help private contractors to recover their investment during the operation phase), and in-kind subsidies (for example, the land where the facility is built). Indirect government support programmes encompass guarantees for different issues such as revenue (government sets a minimum income for the private operator), debt (government secures the borrowings of a private entity), the exchange rate (government hedges private investors from local currency fluctuation risk), interest (government hedges private investors from interest rate fluctuation risk) or tax deductions, among others.

From a theoretical perspective, the distinct analysis of direct and indirect government support in PPPs is paramount. Direct government support, embodied by capital and revenue subsidies, has tangible financial implications for private entities involved in PPPs. Following transaction cost theory, the separation allows researchers to home in on the efficiency of resource allocation, minimize transaction costs, and comprehend the direct financial impact on private participants (Williamson, 2016). Simultaneously, indirect government support, including contingent liabilities and guarantees, reduces uncertainties influencing the overall transaction environment without immediate financial transfers (Hart et al., 1997). Analysing these uncertainties independently provides insights into their impact on transaction efficiency and the risk profile associated with government policies. Some empirical results show evidence to support the theoretical explanations. Wang et al. (2019b) explain that government support programmes increase the financial viability of PPP projects, while Fleta-Asín and Muñoz (2023a) explain that government support programmes reduce PPP uncertainties for the private contractor, lowering transaction costs and increasing private confidence and interest.

Thus, our fourth research hypothesis is.

H4. Government support programmes positively relate to the volume of private investment.

Likewise, many times, infrastructure projects in developing countries are supported by other stakeholders. This is the case with development institutions such as MDBs or the World Bank (also considered an MDB bank that works as a group with more and some different specific purposes). Thus, these institutions support the projects in different ways. Basílio (2017) points out that MDBs contribute to reducing the perception of risk for private contractors, constitute a critical source of funds for projects, and play the role of catalyser for private investments in different ways, such as project design, policy advice, insurance, etc. Similarly, Marcelo and House (2016) explain that MDBs provide financial support (including, capital, equity, and guarantees) and technical support through project preparation assistance. Jandhyala (2016) adds the role of MDBs in solving conflicts between partners during contract enforcement. Fleta-Asín and Muñoz (2023a) note that the support of these institutions reduces transaction costs and makes PPPs more attractive for private investors. Steffen and Schmidt (2019) reveal that MDBs play a fundamental role in renewable energy electricity generation projects in developing countries.

Thus, our fifth research hypothesis is.

H5. Development institutions' support positively relates to the volume of private investment.

Furthermore, Yun et al. (2015) explain that PPPs can be initiated through solicited (the initiative is born in the public sector) or unsolicited proposals (the initiative emerges from the private sector seeking business opportunities). Osei-Kyei et al. (2018) identify that the critical motivations of the public sector for unsolicited proposals are enhanced private sector innovation and creativity in PPPs; lack of public sector capacity to identify, prioritise and procure projects; lack of private investors'/developers' interest in projects in remote areas; and rapid implementation of PPP projects. In unsolicited proposals, the original private proposer directly negotiates with the government, and the process lacks competitiveness (Zawawi et al., 2016). Casady and Baxter (2022) find that unsolicited proposals played a crucial role in the healthcare sector during the period of the Covid-19 pandemic. Unsolicited proposals can also grease the promotion of PPPs, especially in developing countries, due to the lack of a comprehensive policy framework and guidelines for the solicited approach (Xiao and Lam, 2022). In this way, unsolicited proposals emerge as a mechanism that developing countries can use to attract private investment (Osei-Kyei et al., 2018; Hodges, 2003; Mallisetti et al., 2021). Geddes and Wagner (2013) explain that the rise in the complexity and dynamism of PPPs and the outdated procurement laws make it necessary to incentivize the private sector, attracting its interest by providing the flexibility to submit unsolicited proposals.

In this way, our sixth research hypothesis is.

H6. Unsolicited proposals are positively related to the volume of private investment.

2.3. Impact of frameworks' features on private investment

In addressing the critical role of PPP innovation and the influence of frameworks' features on private investment in renewable energy projects, it is important to delve into the multifaceted impact of institutional, economic, and environmental factors. Several researchers defend how the PPP can not only innovate itself as an organization and foster innovations (Link, 2006; Carbonara and Pellegrino, 2020) but can also contribute to sustainable development (Caloffi et al., 2017).

To achieve these objectives, the institutional frameworks, encompassing regulatory structures and government policies, play a pivotal role in shaping the attractiveness of PPPs for renewable energies. Stober et al. (2021) highlight that stable and supportive institutional environments foster private investments in renewable energy ventures. Regulatory clarity and government support create an environment conducive to private investment, ensuring the long-term success of such partnerships.

Economic considerations are equally crucial, influencing project viability and the risk-sharing mechanisms that impact private investment decisions. Ragosa and Warren (2019) provide valuable insights into how economic policies promoting a favourable investment climate positively influence private investment decisions in renewable energy PPPs.

Additionally, the work of Stigka et al. (2014) underscores the significance of environmental acceptance in the success of renewable energy initiatives. Public perception and community support are pivotal factors shaping the sustainability of PPPs for renewable energies.

The framework where the project is performed can significantly impact the interest of private investors in PPP projects. Zhang (2005) points out that governments should endeavour to develop institutional and economic environments that attract private investment to PPPs. Academic literature has identified several risk factors emerging from different environmental dimensions. Thus, the macroeconomic stability of the project's host country has been identified in several studies as a key driver of success for PPPs (Sharma, 2012; Chou and Pramudawardhani, 2015; Cui et al., 2018). Bing et al. (2005) highlight the impact on PPPs' viability in the face of economic risk factors such as poor financial markets, inflation rate volatility, and interest rate volatility, among others. Sounder economic conditions reduce uncertainties surrounding the projects and favour the success of projects (Fleta-Asín and Muñoz, 2020) and the share of private contractors in renewable energy PPPs (Fleta-Asín and Muñoz, 2021). Xu et al. (2019) explain that economic development is the direct driving force for the development of renewable energies. Wang et al. (2021) find that economic growth stimulates renewable energy consumption in China. Similar results are achieved for India by Eren et al. (2019).

Thus, our seventh research hypothesis is.

H7. A sounder economic environment positively relates to the volume of private investment.

Institutional stability is another relevant factor in attracting private investment to PPP projects. Political instability increases uncertainty and leads private contractors to distrust their public partners, who can show unforeseen behaviour during the project execution (Bing et al., 2005). Jimenez and Bayraktar (2020) find that higher political discretionality in the host country is negatively associated with PPPs' performance. Osei-Kyei and Chan (2017) point out that political stability ensures that the government will have a collaborative attitude regarding projects in progress. Fleta-Asín et al. (2022) find that political stability positively impacts the success of the PPP. Rohman (2022) provides empirical evidence supporting that political stability favours the performance of large infrastructure projects. Adebayo (2022) explains that political stability in Canada has helped to attract foreign companies to invest in renewable energies. Xu et al. (2019) highlight that "with the political stability and government credibility of the European region rising year by year, European governments are actively pursuing the status of renewable energy leaders and increasing the energy structure" (p. 12). In this way, despite the slowdown in the economic growth in that region, European renewable energy is developing quickly.

Thus, our eighth research hypothesis is.

H8. Host country institutional stability positively relates to the volume of private investment.

Another feature of the framework to attract private investment to renewable energy PPPs is the relevance of these technologies in the project's host country. The degree of development of renewable energies combines several factors that could be very significant in the attraction of private investment, such as the natural and climatic conditions, the social awareness of these technologies, or the sectorial regulatory framework (Xu et al., 2019). Natural and climatic conditions determine the specific technology promoted (Papież et al., 2018). Furthermore, the development of these technologies could be hampered by natural factors such as topography (Verbruggen et al., 2010). Geophysical factors explain the different levels of implementation of renewable energies across regions in France (Olivier and Del Lo, 2022). Social awareness of the benefits of renewable energies favours the promotion of PPPs for these technologies (Mirza et al., 2009). Social acceptance is identified by several authors as a critical factor determining the development of renewable energies (Pantaleo et al., 2014; Carlisle et al., 2015; Zhao and Chen, 2018). On the same lines, Venugopal and Shukla (2019) explain that a moral engagement with sustainability increases the willingness of energy consumers to pay an increased rate for renewable energy. Besides, a stable regulation on this matter reduces uncertainty and promotes the flourishing of these technologies. In this regard, Talavera et al. (2016) point out that regulatory changes in Spain turned very quickly from a promising scenario into an unstable situation in solar photovoltaic technology. Komendantova et al. (2012) highlight the relevance of stable and predictable regulations to promote the development of renewable energies.

Thus, our ninth research hypothesis is.

H9. Friendlier environments for renewable energies positively relate to the volume of private investment.

2.4. Beyond the direct effects: complementary and substitution effects between the risk allocation strategy and the other factors

Our main interest in this research is how the project risk allocation strategy impacts the volume of private investment in PPPs concerning renewable energies. To enlarge our analyses beyond the direct effect, we explore the potential complementary and/or substitution effects between the transference of project risks to the private partner and the other factors considered relevant in attracting private investment by studying the interaction effects between them. The complementary effect means that the concurrence of transference of more project risks to the private partner and the other factor considered positively interacts with attracting more private investment to the project. The substitution effect would show that the transference of more project responsibilities to the private partner loses relevance to attracting private investment in the presence of other factors or, alternatively, the lack of other factors enhances the relevance of the project risk allocation strategy for the attraction of private interest. Academic literature has analysed potential substitution/complementary effects in PPPs. Wang et al. (2018b) identify that there is both a complementary and a substitution effect between the contract duration and the government subsidy in build-operate-transfer (BOT) projects. Silaghi and Sarkar (2021) determine a substitution effect in the incentives to exert efforts during PPPs' contract enforcement between the regular compensation of the private partner and their compensation upon termination. Basílio (2017) finds empirical evidence of a substitution effect between funds provided by development institutions and private contractors. Fleta-Asín et al. (2022) find complementary and substitution effects between different institutional momenta impacting the performance of PPPs. The support of development institutions becomes more relevant when some institutional factors show weaknesses (Fleta-Asín and Muñoz, 2021). The positive effect of the transference of risk to private partners on PPPs' success is moderated when the project is performed in robust institutional frameworks (Fleta-Asín and Muñoz, 2020). The risk of project failure due to within-country religious diversity is higher when the PPP adopts a greenfield type and when the main sponsor is a foreign company (Jiménez et al., 2019).

Thus, exploration of potential substitution and/or complementary effects will allow us to provide further empirical evidence about the impact of project risk transference strategies on the volume of private investment in PPPs concerning renewable energies. We set out the following research hypothesis.

H10. The transference of project risks to the private partner interacts with other relevant factors impacting the volume of private investment.

Fig. 1 plots the research hypotheses.

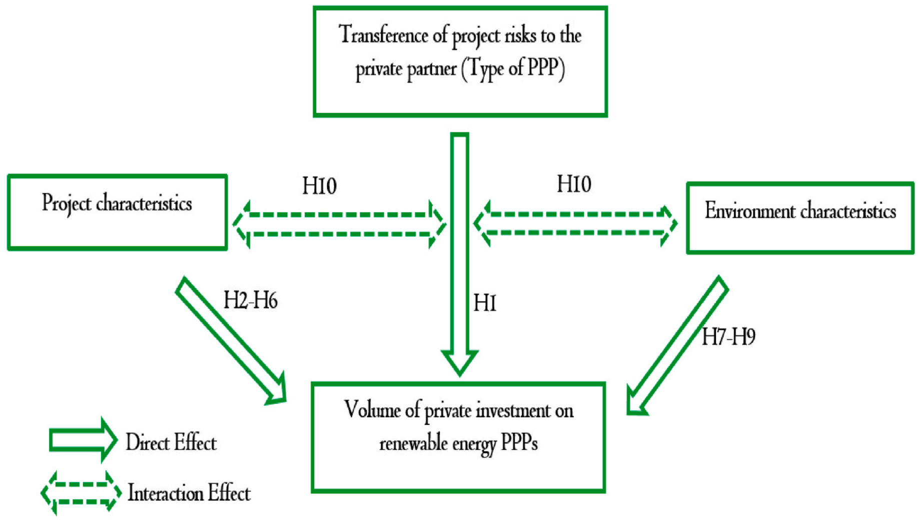

Fig. 1. Research hypotheses.

3. Data and methods

3.1. Data

We analyse a sample formed by 2215 PPPs concerning renewable energies established in 73 developing countries in the period spanning from 1997 to 2019. We obtain the data from different sources. Most of the information is extracted from the Private Participation in Infrastructure (PPI) database from the World Bank. Our dependent variable is the log of private investment (*LogPI*), computed as the log of the product of the percentage of the project owned by the private investor and the total investment, expressed in millions of US dollars.

To approach the level of project risk transferred to the private sector, we use several proxies. The first, TypePPP3, adopts values in the range 1–3, each level representing the different types of PPP explained in the previous section, and higher values meaning more project risks are transferred to the private sector. The second proxy is more accurate and controls for the different subtypes within each category (TypePPP10).[3] Thus, the second proxy adopts values in the range of 1–10, 1(10) meaning fewer (more) project risks transferred to the private sector. These proxies have previously been used in the PPP literature (see Percoco, 2014; Wang et al., 2019a; Fleta-Asín and Muñoz, 2020; see Appendix 1 for more details). These indicators implicitly assume that the rise in the risk transferred to the private sector when moving from one type of PPP to the next is the same. Thus, we build two additional proxies to reflect that this rise could be decreasing or increasing. We apply Napierian logarithms to TypePPP10 to create TypePPP10D, which signifies a diminishing escalation of project risks transferred. Additionally, we formulate TypePPP10I, which inversely mirrors the increments in risk observed in TypePPP10D. This latter indicator denotes a progressive escalation in project risks transferred (Fleta-Asín and Muñoz, 2020). This transformation created proxies that highlight different aspects of risk distribution, catering to various risk attitudes (neutral, risk-averse, and risk-seeking).

We approach the other project factors through a set of dummy variables, adopting the value of 1 when the project has the characteristic and 0 otherwise. Thus, the dummy variable *DirectNeg* adopts the value of 1 when the project has been awarded through a direct negotiation awarding method and 0 otherwise; the dummy variable *Local* adopts the value of 1 when at least one local sponsor participates in the project and 0 otherwise; the dummy variables *DirectGovSupport/IndirectGovSupport* adopt the value of 1 when the PPP is backed for these types of grant and 0 otherwise; the dummy variables *MDB/WB* adopt the value of 1 when the project is supported by MDBs/the World Bank and 0 otherwise; the dummy variable *Unsolicited* adopts the value of 1 when the project initiative arises from the private sector and 0 otherwise.

To approach environmental factors, we use different proxies. For the economic environment, we use the log of GDP per capita obtained from the World Bank. GDP per capita represents the degree of development of the host country. The degree of development of a country is correlated with several economic dimensions relevant to attracting private investment, such as macroeconomic stability, infrastructure endowments, the availability of financial and human resources, etc. Thus, the use of a proxy for this set of factors makes the interpretation of empirical evidence easier and avoids multicollinearity problems in econometric estimations (Fleta-Asín et al., 2020). For political stability, we use the variable *Checks* obtained from the World Bank's Database of Political Institutions. This variable reflects the uncertainty in the institutional environment since it measures the difficulty faced by each one of the country's powers (legislative, executive, or judicial) in making decisions unilaterally (Fleta-Asín and Muñoz, 2023a). For the development of renewable energies in the host country, we use the percentage of total final energy consumption corresponding to renewable energies (*RenewEneComp*) obtained from the World Bank (Anton and Nucu, 2020). A higher percentage of energy consumption from renewable energies would reflect a friendlier environment for renewable energies in different dimensions (geophysical conditions, regulatory framework or social awareness, among others). Since several of these dimensions could be correlated, again the use of one proxy that combines all these matters has advantages from an econometric point of view. Furthermore, and following previous literature, the framework variables are lagged one year (Fleta-Asín et al., 2020).

In addition to the variables pertaining to the research hypotheses, we include several controls in our models. More concretely, we control for

[3] Although this indicator could adopt values between 1 and 10, in our sample, there are not projects at levels 1 and 10. Thus, in the sample analysed, *TypePPP10* ranges between 2 and 9.

Table 1
Summary of variables, definitions, and sources (Part I).

Variable (Hyp.)	Definition	Source
LogPI (H1)	Logarithm of the share of total private investment in millions of American dollars.	Private Participation in Infrastructure (PPI) Project Database
TypePPP3 (H1)	An ordinal variable with values representing the project management types: 1 for management and lease contract, 2 for brownfield, and 3 for greenfield.	
TypePPP10 (H1, H10)	The ordinal variable TypePPP10 encompasses values within the range of 1–10, each corresponding to distinct project types: (1) management contract; (2) lease contract; (3) rehabilitate-operate-transfer (ROT); (4) rehabilitate-lease/rent-transfer (RLT); (5) build-rehabilitate-operate-transfer (BROT); (6) build-lease-transfer (BLT); (7) build-operate-transfer (BOT); (8) build-own-operate; (9) merchant; and (10) rental.	
TypePPP10D (H1)	Napierian logarithm of TypePPP10 to apply a proportional reduction in ordinal distances between categories (i.e. less proportional risk in each increase).	
TypePPP10I (H1)	Reversed Napierian logarithm of TypePP10 to apply a proportional increase in ordinal distances between categories (i.e. higher proportional risk in each echelon).	
DirectNeg (H2, H10)	A dummy variable that adopts the value 1 when the project is awarded through a direct negotiation method, and 0 otherwise.	
Local (H3, H10)	A dummy variable that adopts the value 1 when the project has local sponsor participation, and 0 otherwise.	
DirectGovSupport *IndirectGovSupport* (H4, H10)	A dummy variable that adopts the value 1 when the project has direct government support or indirect government support, and 0 otherwise.	
MDB/WB (H5, H10)	A dummy variable that adopts the value 1 when the project has MDB or World Bank support, and 0 otherwise.	
Unsolicited (H6)	A dummy variable that adopts the value of 1 when the initiative for the project arises in the private sector, and 0 otherwise.	
GDPpercap (H7, H10)	Captures the economic conditions based on the logarithm of the per capita GDP in each country where the project is located.	The World Bank
Checks (H8, H10)	An ordinal integer variable that reflects less (1) to more (18) institutional stability based on the mechanisms or processes in place to ensure a balance of power and prevent the abuse of authority.	The World Bank Database of Political Institutions
RenewEneComp (H9, H10)	Percentage of total final energy consumption corresponding to renewable energies.	The World Bank

Variable	Definition	Source
D97–02 *D03–08* *D09–13*	A dummy variable that adopts the value 1 when the PPP is deployed in the period 1997–2002, 2003–2008 or 2009–2013 respectively, and 0 otherwise. The period 2014–2019 is omitted as the base category.	Private Participation in Infrastructure (PPI) Project Database
DAmerica *DAsia* *DEurope*	A dummy variable that adopts the value 1 when the PPP is located in America, Asia or Europe, respectively, and 0 otherwise. Africa is omitted as the base category.	
DWind *DHydro_Large* *DHydro_Small* *DWaste* *DBiogas* *DBiomass* *DGeothermal*	A dummy variable that adopts the value of 1 when the PPP concerns wind, hydro large, hydro small, waste, biogas, biomass or geothermal, respectively, and 0 otherwise. Solar is omitted as the base category.	
LogCap	Logarithm of the installed capacity of each project.	

Table 2
Summary statistics.

Variable	Obs.	Mean	SD	Min	Max
LogPI	2215	8.633042	1.303372	2.639057	13.51441
TypePPP3	2215	2.916479	0.2879298	1	3
TypePPP10	2215	7.431603	0.9807054	2	9
TypePPP10D	2215	1.994206	0.1650407	0.6931472	2.197225
TypePPP10I	2215	1.780975	0.156644	1.087011	2.098612
DirectNeg	2215	0.1142212	0.3181516	0	1
Local	2215	0.6230248	0.484738	0	1
DirectGovSupport	2215	0.1160271	0.3203297	0	1
IndirectGovSupport	2215	0.2428894	0.4289256	0	1
MDB	2215	0.1801354	0.384387	0	1
WB	2215	0.5223476	0.4996131	0	1
Unsolicited	2215	0.3814898	0.485862	0	1
GDPpercap	2215	8.318032	0.9188815	5.141944	9.589669
Checks	2215	3.45553	2.557149	1	18
RenewEneComp	2215	32.26163	20.20863	0.1773	95.3542
D97-02	2215	0.0564334	0.2308089	0	1
D03-08	2215	0.1534989	0.3605491	0	1
D09-13	2215	0.4	0.4900086	0	1
DEurope	2215	0.0433409	0.2036692	0	1
DAsia	2215	0.5088036	0.5000354	0	1
DAmerica	2215	0.3629797	0.4809676	0	1
DWind	2215	0.276298	0.4472669	0	1
DHydro_Small	2215	0.16614	0.3722903	0	1
DHydro_Large	2215	0.1625282	0.369018	0	1
DWaste	2215	0.0442438	0.2056827	0	1
DBiogas	2215	0.0036117	0.0600027	0	1
DBiomass	2215	0.0659142	0.2481881	0	1
DGeothermal	2215	0.0153499	0.1229679	0	1
LogCap	2215	3.874614	1.489541	−0.6931472	12.06105

This table presents descriptive statistics for the variables used in the models across the analysed sample. For each variable, the table provides the number of observations (Obs.), mean, standard deviation (*SD*), minimum, and maximum values.

Table 3
Correlation matrix (part I).

Variable	LogPI	TypePPP3	TypePPP10	TypePPP10D	TypePPP10I	DirectNeg	Local	DirectGovSupport	IndirectGovSupport	MDB	WB	Unsolicited
TypePPP3	**0.1581**											
TypePPP10	**0.113**	**0.8331**										
TypePPP10D	**0.1245**	**0.8686**	**0.9812**									
TypePPP10I	**0.1008**	**0.7728**	**0.9911**	**0.9496**								
DirectNeg	0.0251	**0.0697**	**0.0591**	**0.0502**	**0.0593**							
Local	**−0.1534**	0.0235	**−0.0481**	−0.0342	**−0.0623**	**0.045**						
DirectGovSupport	−0.0005	**0.0512**	**−0.0991**	**−0.084**	**−0.1191**	0.025	**0.18**					
IndirectGovSupport	**0.0833**	**0.1643**	**0.1845**	**0.1774**	**0.1796**	**0.0746**	**−0.0482**	**−0.1822**				
MDB	**0.1359**	0.0013	**0.0477**	**0.0416**	**0.0521**	0.009	**−0.1614**	**−0.0744**	**0.0934**			
WB	**0.2671**	**0.0805**	**0.1923**	**0.1727**	**0.2051**	0.0337	**−0.147**	**−0.1954**	**0.099**	**0.3377**		
Unsolicited	**−0.1266**	**0.0567**	**0.0429**	0.0315	**0.0508**	**−0.0541**	0.0145	**−0.1684**	**−0.2368**	**−0.0852**	**−0.0361**	
GDPpercap	**0.207**	**−0.1204**	**−0.07**	**−0.0712**	**−0.0626**	**−0.2587**	0.0066	**0.1035**	−0.0018	**−0.1055**	−0.0042	**−0.2068**
Checks	−0.0249	**−0.0784**	0.0181	0.0126	0.0281	0.0343	**−0.0593**	**−0.241**	**−0.0354**	**−0.0394**	**0.1446**	**0.2032**
RenewEneComp	**−0.1387**	**−0.0973**	**−0.0859**	**−0.0732**	**−0.0893**	**0.0751**	**−0.0535**	**−0.2607**	0.0291	−0.012	**0.1021**	**0.2638**
D97-02	**−0.1327**	**−0.1873**	**−0.1595**	**−0.1605**	**−0.1462**	**−0.0509**	**−0.0601**	**−0.0886**	**−0.134**	0.0126	**−0.0912**	**0.2308**
D03-08	**−0.179**	**−0.1027**	**−0.1364**	**−0.1229**	**−0.1385**	0.0006	**0.0883**	**−0.1543**	**−0.212**	**−0.0823**	**−0.0792**	**0.4417**
D09-13	0.0317	**0.0384**	0.0024	0.0059	−0.0066	**0.1906**	**0.1274**	**0.1876**	**0.3047**	**−0.0614**	**−0.0494**	**−0.2296**
DEurope	**−0.0823**	0.0309	**0.0782**	**0.0595**	**0.0892**	**0.0351**	**−0.1044**	−0.0217	**0.0604**	**0.0502**	**−0.0583**	**−0.0531**
DAsia	**−0.1096**	**0.1824**	**0.0447**	**0.0494**	0.0285	**0.174**	**0.2755**	**0.2911**	0.0027	**−0.1058**	**−0.1676**	**−0.0557**
DAmerica	**0.0849**	**−0.2441**	**−0.1494**	**−0.1399**	**−0.1392**	**−0.1943**	**−0.1761**	**−0.2471**	**−0.0729**	−0.0216	**0.0959**	**0.1204**
DWind	**0.1995**	**0.1477**	**0.2387**	**0.2141**	**0.2487**	**0.0638**	**−0.0527**	**−0.0725**	**0.1068**	−0.0111	**0.1583**	**−0.0571**
DHydro_Small	**0.1455**	**−0.4815**	**−0.4686**	**−0.4322**	**−0.464**	−0.0078	−0.0282	**−0.1276**	**−0.1312**	0.0022	−0.0248	**0.0964**
DHydro_Large	**−0.3319**	**0.0428**	**−0.1041**	**−0.1018**	**−0.1144**	**−0.0543**	**0.07**	**−0.0679**	−0.0041	**−0.0791**	**−0.0834**	**0.2385**
DWaste	**−0.0709**	**0.0624**	**0.0643**	**0.0621**	**0.0637**	−0.0013	**0.0903**	**0.0523**	**−0.1116**	**−0.078**	**−0.0536**	**0.1248**
DBiogas	**−0.0669**	0.0175	0.0349	0.0304	**0.0383**	0.0257	0.0158	0.0017	−0.0341	0.0109	−0.0328	−0.0008
DBiomass	**−0.0663**	**0.0771**	**0.0575**	**0.0601**	**0.0516**	−0.0039	**0.0715**	**0.2049**	−0.0147	**−0.0819**	**−0.1649**	**−0.0775**
DGeothermal	**0.1016**	**−0.0403**	−0.0138	−0.0192	−0.0069	−0.0102	−0.009	−0.0338	0.0149	**0.0848**	**0.0532**	**0.0834**
LogCap	**0.6227**	**−0.375**	**−0.3046**	**−0.2726**	**−0.3004**	**−0.0498**	**−0.1592**	**−0.1067**	**−0.0948**	**0.0496**	**0.1275**	**−0.075**

Variable	GDPpercap	Checks	RenewEneComp	D97-02	D03-08	D09-13	DEurope	DAsia	DAmerica
Checks	**−0.1265**								
RenewEneComp	**−0.5052**	**0.3438**							
D97-02	**−0.1634**	**0.0452**	**0.1068**						
D03-08	**−0.3151**	**0.2112**	**0.2579**	**−0.1041**					
D09-13	**0.1071**	−0.0337	−0.0045	**−0.1997**	**−0.3477**				
DEurope	**0.0501**	**−0.0674**	**−0.2202**	**−0.0424**	**−0.0599**	**0.057**			
DAsia	**−0.412**	**−0.1813**	**−0.1375**	**−0.1002**	0.005	**0.0981**	**−0.2166**		
DAmerica	**0.4605**	**0.3099**	**0.2249**	**0.149**	**0.064**	**−0.1008**	**−0.1607**	**−0.7683**	
DWind	**0.1047**	0.0317	**−0.1042**	**−0.1205**	**−0.0867**	**0.0519**	**−0.0373**	−0.0089	0.0291
DHydro_Small	**−0.0469**	**0.1586**	**0.2562**	**0.2535**	**0.244**	**−0.0475**	**−0.0712**	**−0.1559**	**0.2533**
DHydro_Large	**−0.1845**	**0.0924**	**0.3039**	**0.0407**	**0.1621**	**0.045**	−0.0277	−0.0029	**0.0365**
DWaste	−0.0198	0.014	0.0115	**0.0711**	**0.1033**	**−0.0636**	**−0.0458**	0.027	0.002
DBiogas	**0.0423**	−0.0225	**−0.0656**	−0.0147	−0.0256	0.0277	**0.0981**	−0.0011	**−0.0454**
DBiomass	**0.1195**	**−0.0879**	**−0.0633**	**−0.065**	**−0.0879**	**0.1136**	**−0.0476**	**0.0754**	−0.0265
DGeothermal	**−0.0556**	−0.0294	0.0308	**0.0968**	0.008	−0.027	−0.0266	**0.0566**	**−0.0484**
LogCap	**0.1883**	**0.1065**	0.0346	**0.0826**	**0.0393**	**−0.108**	**−0.131**	**−0.262**	**0.339**

Variable	DWind	DHydro_Small	DHydro_Large	DWaste	DBiogas	DBiomass	DGeothermal
DHydro_Small	**−0.2758**						
DHydro_Large	**−0.2722**	**−0.1966**					
DWaste	**−0.1329**	**−0.096**	**−0.0948**				
DBiogas	**−0.0372**	−0.0269	−0.0265	−0.013			
DBiomass	**−0.1641**	**−0.1186**	**−0.117**	**−0.0572**	−0.016		
DGeothermal	**−0.0771**	**−0.0557**	**−0.055**	−0.0269	−0.0075	−0.0332	
LogCap	**0.0708**	**0.576**	**−0.3648**	**−0.0899**	**−0.1023**	**−0.0807**	0.0269

Table 3 displays the correlation matrix for the variables considered in the models across the analysed sample. Variables marked in bold have correlations with intersecting variables above the 10 per cent threshold, providing insight into statistically significant associations within the dataset time, geographical and technological idiosyncrasies through several dummy variables. We include the time dummy variables *D97–02*, *D03–08* and *D09–13* that adopt the value of 1 when the project is established in that period and 0 otherwise (we take the period 2014–2019 as the base category to avoid multicollinearity problems). We also consider the dummy variables *DEurope*, *DAsia* and *DAmerica* that take the value of 1 when the project is performed on that continent and 0 otherwise (we establish Africa as the base category to avoid multicollinearity problems). To control for technologies, we add the dummy variables *DWind*, *DHydro_Large*, *DHydro_Small*, *DWaste*, *DBiogas*, *DBiomass* and *DGeothermal* that adopt the value of 1 when the project belongs to that technology and 0 otherwise (we take solar as the base category to avoid multicollinearity problems). Finally, we consider the size of the project approached by the log of the installed capacity (*LogCap*) since it is reasonable to expect that the size of the facility will determine the volume of investment required.

Table 1 shows the variables used, their description and source. Table 2 provides the summary statistics for the variables considered across models and Table 3 provides the matrix correlation. Fig. 2 plots the distribution of projects in our sample across countries.

3.2. Methods

We run several regressions to test the research hypotheses. Since our data have a hierarchical structure of projects performed within countries, and given the continuous nature of our dependent variable (*LogPI*), we run generalized linear models (GLM) with multilevel fixed effects, which means that intercepts of regressions can vary across countries. This estimation technique allows us to achieve more accurate empirical evidence, since it controls for host countries' idiosyncrasies not explicitly included across models (Fleta-Asín and Muñoz, 2023b). Following previous literature, we first estimate the base model including only controls and subsequently we add the different proxies to test the research hypotheses (Fleta-Asín and Muñoz, 2020). The base model is as follows:

$$\begin{aligned} LogPI_{i,j,t} = {} & \alpha + \beta_1 D97-02_{i,j,t} + \beta_2 D03-08_{i,j,t} + \beta_3 D09-13_{i,j,t} \\ & + \beta_4 DEurope_{i,j,t} + \beta_5 DAsia_{i,j,t} + \beta_6 DAmerica_{i,j,t} + \beta_7 DWind_{i,j,t} \\ & + \beta_8 DHydro_{Small\,i,j,t} + \beta_9 DHydro_{Large\,i,j,t} + \beta_{10} DWaste_{i,j,t} + \beta_{11} DBiogas_{i,j,t} \\ & + \beta_{12} DBiomass_{i,j,t} + \beta_{13} DGeothermal_{i,j,t} + \beta_{14} LogCap_{i,j,t} + u_j + \varepsilon_{i,j} \end{aligned} \tag{1}$$

where *LogPI* represents the log of total private investment of project i

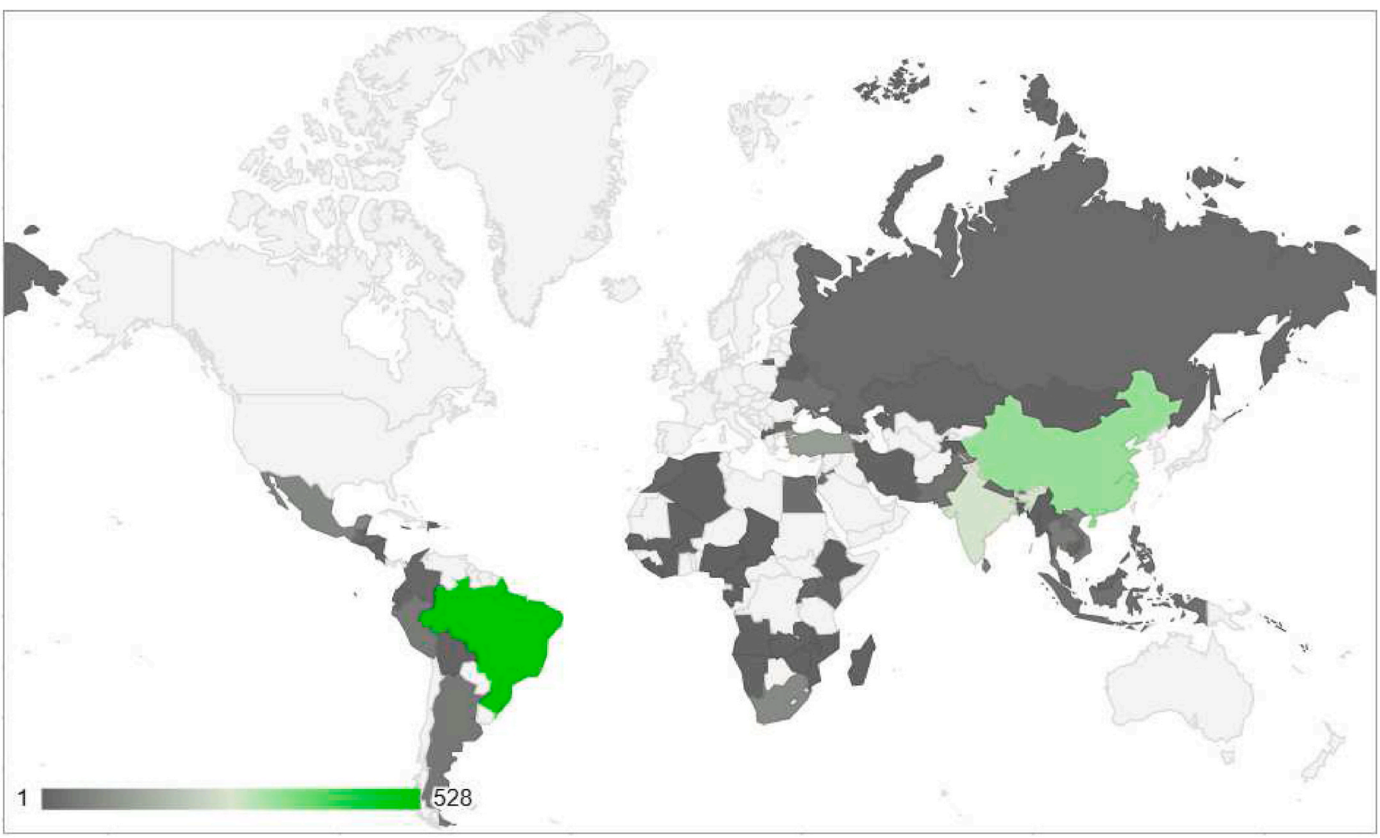

Fig. 2. Distribution of renewable energy PPPs across countries.

established in country j in the year t; subsequently, control variables for time, continent, technology and size of the facility promoted appear; u_j reflects the unobserved country effects impacting all the projects belonging to the same country; and $\varepsilon_{i,j}$ represents the unobserved project effects.

To test H1, we include in the base model the different proxies for the risk transferred to the private sector. Equations (2)–(5) show these models:

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP3_{i,j,t} + u_j + \varepsilon_{i,j} \quad (2)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + u_j + \varepsilon_{i,j} \quad (3)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10D_{i,j,t} + u_j + \varepsilon_{i,j} \quad (4)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10I_{i,j,t} + u_j + \varepsilon_{i,j} \quad (5)$$

To test H2–H9, we add the different proxies to model 3. We subsequently add the proxies involved in the different research hypotheses. Once we have tested the different proxies for the risk allocation strategy, we use TypePPP10 in the remaining models since it is more accurate and identifies more specific types of PPP.[4]

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + u_j + \varepsilon_{i,j} \quad (6)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + u_j + \varepsilon_{i,j} \quad (7)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + \beta_{18}DirectGovSupport_{i,j,t} + \beta_{19}IndirectGovSupport_{i,j,t} + u_j + \varepsilon_{i,j} \quad (8)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + \beta_{18}DirectGovSupport_{i,j,t} + \beta_{19}IndirectGovSupport_{i,j,t} + \beta_{20}MDB_{i,j,t} + \beta_{21}WB_{i,j,t} + u_j + \varepsilon_{i,j} \quad (9)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + \beta_{18}DirectGovSupport_{i,j,t} + \beta_{19}IndirectGovSupport_{i,j,t} + \beta_{20}MDB_{i,j,t} + \beta_{21}WB_{i,j,t} + \beta_{22}Unsolicited_{i,j,t} + u_j + \varepsilon_{i,j} \quad (10)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + \beta_{18}DirectGovSupport_{i,j,t} + \beta_{19}IndirectGovSupport_{i,j,t} + \beta_{20}MDB_{i,j,t} + \beta_{21}WB_{i,j,t} + \beta_{22}Unsolicited_{i,j,t} + \beta_{23}GDPpercap_{i,j,t-1} + u_j + \varepsilon_{i,j} \quad (11)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + \beta_{18}DirectGovSupport_{i,j,t} + \beta_{19}IndirectGovSupport_{i,j,t} + \beta_{20}MDB_{i,j,t} + \beta_{21}WB_{i,j,t} + \beta_{22}Unsolicited_{i,j,t} + \beta_{23}GDPpercap_{i,j,t-1} + \beta_{24}Checks_{i,j,t-1} + u_j + \varepsilon_{i,j} \quad (12)$$

$$LogPI_{i,j,t} = BASE\ Model + \beta_{15}TypePPP10_{i,j,t} + \beta_{16}DirectNeg_{i,j,t} + \beta_{17}Local_{i,j,t} + \beta_{18}DirectGovSupport_{i,j,t} + \beta_{19}IndirectGovSupport_{i,j,t} + \beta_{20}MDB_{i,j,t} + \beta_{21}WB_{i,j,t} + \beta_{22}Unsolicited_{i,j,t} + \beta_{23}GDPpercap_{i,j,t-1} + \beta_{24}Checks_{i,j,t-1} + \beta_{25}RenewEneComp_{i,j,t-1} + u_j + \varepsilon_{i,j} \quad (13)$$

Finally, to test H10, we perform several models in which we include the interaction term between TypePPP10 and the different factors considered in Equation (13). For the variables involved in interactions that are not dummy variables, we use mean-centred values to avoid multicollinearity problems (Aiken et al., 1991; Fleta-Asín et al., 2022).

$$LogPI_{i,j,t} = Equation\ (13) + \beta_{26}TypePPP10_{i,j,t}{*}Project\_Factor_{i,j,t} + u_j + \varepsilon_{i,j} \quad (14)$$

$$LogPI_{i,j,t} = Equation\ (13) + \beta_{26}TypePPP10_{i,j,t}{*}Framework\_Factor_{i,j,t-1} + u_j + \varepsilon_{i,j} \quad (15)$$

4. Empirical findings and discussion

Table 4 reports the estimated coefficients for the base model and the models testing H1.

For each model, the estimated coefficients from a GLM multilevel mixed-effects estimation technique are reported, together with the robust standard errors and several diagnostic tests. More concretely, the Wald $\chi2$ statistic is reported, which assesses the reliability of the independent variables; the likelihood ratio (LR) test, which verifies that the multilevel approach is appropriate; and the mean-variance inflation factor (VIF), which evaluates the presence of multicollinearity issues. In all models, the diagnostic tests lead us to reject the null hypothesis that all the coefficients are simultaneously equal to zero (Wald χ^2 statistic), to accept that a multilevel approach is preferred to a linear one (LR test), and to reject the existence of multicollinearity problems (mean VIFs below the stricter limit of 5 set out by Hair et al., 1998).[5]

The coefficients derived from the base model (model 1) reveal certain attributes of the renewable energy PPPs within our dataset. Thus, those projects performed more recently, outside Europe, related to geothermal technology, and involving facilities with more capacity attract more private investment. H1 is tested through models 2–5. In these models, we add the different proxies of project risk allocation strategies to the base model. In all cases, the estimated coefficient on the project risk allocation strategy proxy adopts a positive and significant value—i.e., for the proxy classifying projects in three types of PPP (TypePPP3, model 2); for the proxy considering ten types of PPP (TypePPP10, model 3); for the proxy considering that the increase in project risk transferred to the private sector when moving from one PPP type to the following one is reducing (TypePPP10D, model 4); and for the proxy considering that the increase in project risk transferred to the private sector when moving from one PPP type to the following one is increasing (TypePPP10I, model 5). This means that we cannot reject H1. In this way, we can conclude that establishing PPP types in which the government transfers more project risks to the private sector is effective to attract private investment in renewable energy projects.

These empirical findings endorse the reasoning developed in section 2. Bundling responsibilities in the private partner alleviates opportunistic behaviours of the private partner consisting of underinvesting during the construction phase of the project, since it would jeopardize the private contractor's interests during the operation phase (Nisar, 2007). The temporary allocation of greater property rights to the private

[4] For the sake of brevity, we focus on the results achieved when using TypePPP10. However, when using the other proxies for risk allocation strategy, the results achieved across models mostly hold.

[5] The same conclusions are reached for the models reported in the other tables.

Table 4
Impact of risk allocation strategies on the volume of private investment in renewable energy PPPs.

	Model 1 (Base Model)	Model 2 TypePPP3	Model 3 TypePPP10	Model 4 TypePPP10D	Model 5 TypePPP10I
PPPType		1.751***	0.359**	1.944**	2.133**
		(3.07)	(2.36)	(2.08)	(2.36)
D97-02	−0.801***	−0.673***	−0.769***	−0.754***	−0.790***
	(−4.43)	(−3.85)	(−4.09)	(−4.03)	(−4.18)
D03-08	−0.467***	−0.482***	−0.491***	−0.486***	−0.493***
	(−2.86)	(−3.54)	(−3.38)	(−3.36)	(−3.33)
D09-13	0.090*	0.091	0.106**	0.099*	0.111***
	(1.71)	(1.5)	(2.09)	(1.92)	(2.21)
DEurope	−0.366***	−0.279**	−0.360**	−0.334***	−0.383***
	(−2.91)	(−2.43)	(−2.91)	(−2.93)	(−2.85)
DAsia	−0.094	−0.142	−0.075	−0.072	−0.076
	(−0.7)	(−1.26)	(−0.55)	(−0.53)	(−0.55)
DAmerica	−0.097	−0.102	−0.130	−0.118	−0.138
	(−0.97)	(−1.01)	(−1.17)	(−1.1)	(−1.22)
DWind	0.175	0.106	0.125	0.136	0.126
	(1.39)	(1.16)	(1.27)	(1.32)	(1.27)
DHydro_Large	−0.587	−0.120	−0.187	−0.249	−0.204
	(−1.36)	(−0.68)	(−0.88)	(−1.07)	(−0.92)
DHydro_Small	−0.103	0.003	0.159	0.119	0.159
	(−1.22)	(0.03)	(1.19)	(1.01)	(1.15)
DWaste	0.142	0.081	0.073	0.089	0.070
	(0.48)	(0.25)	(0.22)	(0.28)	(0.2)
DBiogas	−0.096	−0.072	−0.127	−0.139	−0.125
	(−0.31)	(−0.33)	(−0.44)	(−0.49)	(−0.41)
DBiomass	−0.143	−0.203	−0.230*	−0.207	−0.235
	(−1.54)	(−1.51)	(−1.69)	(−1.63)	(−1.71)
DGeothermal	0.585***	0.863***	0.821***	0.781***	0.810***
	(5.21)	(4.45)	(5.18)	(5.55)	(5.27)
LogCap	0.652***	0.705***	0.680***	0.673***	0.679***
	(7.21)	(14.49)	(10.99)	(10.33)	(10.62)
Intercept	6.538***	1.103	3.599***	2.441	2.479
	(19.07)	(0.65)	(3.37)	(1.35)	(1.64)
Prob > χ^2	1326.02***	2867.23***	2819.21***	2401.11***	3125***
LR Test	136.60***	133.44***	146.96***	147.16***	148.46***
VIF	1.83	1.82	1.83	1.82	1.83
Pseudo-R^2	0.7563	0.8201	0.7854	0.7832	0.7814
Obs.	2215	2215	2215	2215	2215

The regression coefficients represent the estimated effect of each variable on private investment volume. T-statistics computed from robust standard errors are given in parentheses. Additionally, the table includes key statistical measures such as the probability value (Prob > χ2), likelihood ratio test (LR test), variance inflation factor (VIF), Pseudo-R^2, and the number of observations (Obs.). Notable findings include the statistically significant coefficients, with significance levels denoted as *** (1%), ** (5%), and * (10%). The likelihood ratio tests demonstrate the overall model fit, while the Pseudo-R^2 values indicate the proportion of variance explained by each model.

contractor that occurs under PPP types where the private partner takes more responsibilities broadens the scope of activities in which private involvement can contribute to enhancing efficiency and ameliorates the conditions in which the private contractor operates the assets (Grossman and Hart, 1986; Hart et al., 1997; Hart, 2003; Wang et al., 2018a). PPPs in which the private partner can participate in more activities could be more attractive for private investment due to more opportunities to do business. All these factors incentivize private companies to invest in PPPs concerning renewable energies.

Table 5 reports the results for models 6–13 that allow us to contrast H2–H9.

Model 6 supplements the existing model, which includes controls and TypePPP10, with an additional proxy to account for the awarding method. We observe that the estimated coefficient on the incorporated variable is positive and significant, meaning that those projects awarded through a direct negotiation method attract more private investment. This leads us not to reject H2. A direct negotiation method can attract more interest from private investors than a competitive awarding method due to the expectation of achieving better conditions in a tendering process without competitive pressure which could yield extraordinary profits during project execution (Cunha-Marques and Berg, 2011; Soomro and Zhang, 2016).

Model 7 adds to model 6 the proxy for controlling the presence of a local sponsor in the project. The estimated coefficient on *Local* is negative but non-significant. This leads us to reject H3. Contrary to our expectation, the participation of a local sponsor does not impact the attraction of private investment to renewable energy PPPs. Academic literature has explained the positive participation of a local sponsor since it reduces the liability of foreignness suffered by foreign investors (Jiménez et al., 2017). However, this empirical evidence is not explicitly related to renewable energy PPPs. In fact, in a sample of renewable energy PPPs, Fleta-Asín and Muñoz (2021) do not find a significant impact of local sponsors on the percentage of the project company that is owned by private sponsors.

Model 8 adds to model 7 the proxies for the existence of government support programmes backing the PPPs. The estimated coefficients on both *DirectGovSupport* and *IndirectGovSupport* are positive and significant. This allows us not to reject H4. The existence of different kinds of government support programmes reduces the uncertainties faced by private investors. These guarantees reduce the likelihood of private contractors' losses during contract enforcement, which spurs private interest to engage in PPPs (Wang et al., 2019b).

Model 9 adds to model 8 the variables to test H5. We employ two proxies *MDB* and *WB*, that are dummy variables adopting a value of 1 when the project receives some kind of support from MDBs or the World Bank. The estimated coefficients on both variables are positive but are significant only in the case of the World Bank. This allows us not to reject H5, at least for the WB proxy. Similarly to the case of the government support programmes, the support of development institutions reduces uncertainties surrounding the projects, leading to a fall in the

Table 5
Impact of other factors on the volume of private investment in renewable energy PPPs.

	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
PPPType10	0.359** (2.36)	0.359** (2.36)	0.356** (2.38)	0.338** (2.42)	0.312** (2.57)	0.313** (2.58)	0.313** (2.58)	0.309** (2.57)
DirectNeg	0.132** (2.05)	0.134** (2.04)	0.127** (2.16)	0.118** (1.97)	0.120* (1.95)	0.136** (2.26)	0.158*** (2.63)	0.149** (2.58)
Local		−0.024 (−0.43)	−0.027 (−0.48)	−0.016 (−0.28)	−0.009 (−0.16)	−0.021 (−0.39)	−0.012 (−0.22)	−0.008 (−0.15)
DirectGovSupport			0.220** (2.31)	0.212** (2.24)	0.233** (2.26)	0.215** (2.22)	0.216** (2.3)	0.228** (2.27)
IndirectGovSupport			0.187*** (5.04)	0.183*** (4.42)	0.233*** (5.14)	0.240*** (5.43)	0.237*** (5.54)	0.243*** (5.73)
MDB				0.074 (1.36)	0.078 (1.45)	0.088* (1.65)	0.089* (1.67)	0.096* (1.85)
WB				0.325** (2.06)	0.331** (2.08)	0.335** (2.17)	0.340** (2.22)	0.343** (2.32)
Unsolicited					0.245** (2.56)	0.272*** (2.8)	0.255*** (2.65)	0.258*** (2.84)
GDPpercap						0.295* (1.88)	0.295** (1.97)	0.492*** (3.01)
Checks							0.034*** (5.05)	0.030*** (5.54)
RenewEneComp								0.013** (2.47)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Prob > χ^2	3275.29***	3610.22***	4353.07***	7030.92***	6520.01***	6809.74***	7673.72***	10,130.53***
LR Test	152.28***	149.12***	139.38***	168.95***	179.43***	167.52***	176.81***	189.94***
VIF	1.79	1.76	1.73	1.71	1.73	1.8	1.81	1.97
Pseudo-R^2	0.7856	0.7856	0.7878	0.7956	0.7986	0.8034	0.8052	0.8080
Obs.	2215	2215	2215	2215	2215	2215	2215	2215

The regression coefficients indicate the estimated effect of each variable on private investment volume, with t-statistics computed from robust standard errors presented in parentheses. The table also includes essential statistical measures such as the probability value (prob > χ2), likelihood ratio test (LR test), variance inflation factor (VIF), Pseudo-R2, and the number of observations (Obs.). Noteworthy results are denoted with significance levels: *** (1%), ** (5%), and * (10%). The likelihood ratio tests evaluate the overall model fit, while Pseudo-R^2 values indicate the proportion of variance explained.

transaction costs faced by private contractors involved in these projects (Fleta-Asín and Muñoz, 2023a).

Model 10 adds to Model 9 the *Unsolicited* variable that allows us to test H6. The estimated coefficient of the variable included is positive and significant, meaning that those projects whose initiative arises in the private sector attract more private investment. This leads us not to reject H6. When the initiative for the project arises in the private sector, the private contractor is usually selected through a direct negotiation method (Zawawi et al., 2016). Besides, the private contractor enjoys more influence when defining the details and technical issues of the project that subsequently might yield more benefits for it. Unsolicited mechanisms are also very useful to attract private investment where the host country lacks solid procedures to promote solicited PPPs, which is frequent in developing countries (Xiao and Lam, 2022).

Model 11 allows us to test H7 by incorporating as an independent variable the degree of development of the host country through the log of the GDP per capita. The estimated coefficient on this proxy is positive and significant, meaning that greater economic development positively relates to the volume of private investment in renewable energy PPPs. Thus, we cannot reject H7. This result is not surprising given the empirical evidence provided by the PPPs literature. Greater economic development is positively correlated with macroeconomic stability, infrastructure endowment, and the availability of financial and human resources, all of these being factors that grease the promotion and development of investments (Fleta-Asín et al., 2020).

Model 12 adds to model 11the variable *Checks*, which approaches the institutional stability of the host country and tests H8. The estimated coefficient on *Checks* is positive and significant, which leads us not to reject H8. This finding shows that the greater the institutional stability, the more private investment is attracted to renewable energy PPPs. Operating in a stable institutional environment means a more trustworthy public partner, which reduces uncertainty and the transaction costs faced by the private partner, fostering private companies' willingness to engage in renewable energy investments (Xu et al., 2019; Adebayo, 2022).

Finally, model 13 includes the variable *RenewEneComp* that combines several geophysical, institutional, and social factors specifically related to renewable energies. The estimated coefficient on this variable is positive and significant, meaning that those projects performed in countries where renewable energies are more present attract more private investment. Factors such as the geophysical conditions, the regulatory body on renewable energies, and social awareness of these technologies can determine the success and profitability of the renewable energy PPPs when raising the interest of private investors (Komendantova et al., 2012; Pantaleo et al., 2014; Carlisle et al., 2015; Zhao and Chen, 2018; Olivier and Del Lo, 2022).

To further analyse the impact of project risk allocation strategies on private investment's attraction to renewable energy PPPs, we explore the existence of substitution and/or complementary effects between the level of project risk transferred to the private sector and the other factors determining the volume of private investment. Table 6 reports the results for models 14–23 in which we interact the risk indicator TypePPP10 with the remaining factors analysed.

Models 14–20 report the results when interacting TypePPP10 with each of the other project characteristics tested in the research hypotheses (H2–H6). As can be seen, the estimated coefficients in the interaction terms are negative in all cases, and in five out of seven models are also significant. More concretely, we obtain negative and significant results when interacting TypePPP10 with an awarding method based on direct negotiation (model 14), local sponsor participation (model 15), the existence of direct government support programmes (model 16), the support of the World Bank (model 19), and the initiative of the project emerging in the private sector (model 20). This means that there is a substitution effect between promoting PPP types in which the private investor takes more project responsibilities and the rest of the project's characteristics that have a positive effect on attracting private investment to renewable energy PPPs. That is to say, bundling more responsibilities in the private partner is more relevant to attract a greater volume of private investment when a direct negotiation method is not employed, the support of the government and/or the World Bank is lacking, and the project initiative is taken by the public sector. Note that although the direct effect of local sponsor participation was not significant (model 7 in Table 5), the interaction effect between TypePPP10 and *Local* is. This means that the presence of a local sponsor in the project affects the impact of the project risk transferred to the private sector on the attraction of private investment. In particular, when a local sponsor is involved in the project, the promotion of PPP types where private investment assumes increased responsibilities diminishes their effectiveness in attracting private investment. That is to say, the presence of a local sponsor could reduce the liability of foreignness faced by foreign investors, so these foreign investors could be willing to invest in PPP types although these types involve a lower allocation of property rights over project assets, which worsens the conditions in which the private contractor can perform the project and reduces the scope of activities in which the private investor can participate. In this way, the participation of local sponsors could make projects with a priori lower

Table 6
(Part I). Interaction effects between risk allocation strategies and the other factors.

	Model 14	Model 15	Model 16	Model 17	Model 18
PPPType10	0.331** (2.59)	0.448*** (2.99)	0.359*** (3.22)	0.315** (2.59)	0.319** (2.58)
DirectNeg	0.176** (2.22)				
Local		0.007 (0.14)			
DirectGovSupport			0.168** (2.45)		
IndirectGovSupport				0.303*** (3.99)	
MDB					0.101* (1.81)
Interaction	−0.229* (−1.83)	−0.238*** (−2.78)	−0.395*** (−3.58)	−0.203 (−1.32)	−0.061 (−1.33)
Control Variables	YES	YES	YES	YES	YES
Project Characteristics	YES	YES	YES	YES	YES
Environment Characteristics	YES	YES	YES	YES	YES
Prob > χ^2	10,580.58***	10,683.82***	15,691.43***	11,298.07***	10,564.45***
LR Test	176.03***	200.48***	185.28***	177.98***	188.85***
VIF	1.95	2.06	1.95	1.99	1.96
Pseudo-R^2	0.809	0.8128	0.8122	0.8084	0.8081
Obs.	2215	2215	2215	2215	2215
	Model 19	**Model 20**	**Model 21**	**Model 22**	**Model 23**
PPPType10	0.355*** (2.76)	0.500*** (3.15)	0.292** (2.53)	0.322*** (3.74)	0.318*** (3.51)
WB	0.344*** (2.65)				
Unsolicited		0.234*** (4)			
GDPpercap			0.499*** (2.72)		
Checks				0.017* (1.83)	
RenewEneComp					0.013** (2.43)
Interaction	−0.112** (−2.41)	−0.380*** (−2.96)	0.094 (1.49)	0.073 (1.45)	0.007* (1.92)
Control Variables	YES	YES	YES	YES	YES
Project Characteristics	YES	YES	YES	YES	YES
Environment Characteristics	YES	YES	YES	YES	YES
Prob > χ^2	9756.44***	8740.83***	13,064.23***	12,808.29***	9438.73***
LR Test	185.09***	176.42***	169.04***	159.17***	205.46***
VIF	2	2.02	1.94	1.95	1.95
Pseudo-R^2	0.8087	0.817	0.8097	0.8134	0.8139
Obs.	2215	2215	2215	2215	2215

The coefficients for interaction terms represent the change in the impact of risk allocation strategies due to the presence of other factors. T-statistics computed from robust standard errors are provided in parentheses. The table includes essential statistical measures such as the probability value (prob > χ2), likelihood ratio test (LR test), variance inflation factor (VIF), Pseudo-R^2, and the number of observations (Obs.). Key findings are denoted with significance levels: *** (1%), ** (5%), and * (10%). The likelihood ratio tests assess the overall model fit, while Pseudo-R^2 values indicate the proportion of variance explained.

potential to do business due to the public sector retaining more tasks attractive for foreign investors.

Models 21–23 report the results when interacting TypePPP10 with the framework factors. As can be seen, the estimated coefficient on the interaction terms is positive in all cases, but it is only significant in model 23 when interacting the risk transferred to the private sector with *RenewEneComp*. This finding reveals a complementary effect between the type of PPP performed and the degree of development of renewable energies in the host country. When the project is performed in an environment that is friendlier to renewable energies, the positive effect of bundling responsibilities in the private partner to attract private investment is intensified.

To further analyse the substitution/complementary effects between TypePPP10 and the other factors, Tables 7 and 8 report the marginal effects of TypePPP10 on the dependent variable (volume of private investment) when the dummy variables (continuous variables) adopt the values of 1 and 0 (one standard deviation below or above the mean). Appendix 2 plots these effects.

Table 7 shows that for all the other projects characteristics a substitution effect occurs with TypePPP10. Thus, we can see that the positive impact of bundling more responsibilities in the private partner on the volume of private investment is greater when the dummy variables

Table 7
Marginal effects for TypePPP10 interacting with the other project characteristics (Models 14–20).

	Model 14 DirectNeg	Model 15 Local	Model 16 DirectGovSupport	Model 17 IndirectGovSupport	Model 18 MDB	Model 19 WB	Model 20 Unsolicited
Dummy Variable (0)	0.331** (2.59)	0.448*** (2.99)	0.359*** (3.22)	0.315** (2.59)	0.319** (2.58)	0.355*** (2.76)	0.500*** (3.15)
Dummy Variable (1)	0.101 (1.33)	0.210** (2.25)	−0.036 (−0.76)	0.113 (1.21)	0.259** (2.17)	0.243** (2.18)	0.119 (2.56)

The coefficients are presented with t-statistics computed from robust standard errors in parentheses. Key findings are denoted with significance levels: *** (1%), ** (5%), and * (10%). The marginal effects provide insights into how the interaction between TypePPP10 and specific project characteristics influences the outcome.

Table 8
Marginal effects for TypePPP10 interacting with the environment characteristics (models 21–23).

	Model 21 GDPpercap	Model 22 Checks	Model 23 RenewEneComp
−1 SD below the mean	0.206** (2.53)	0.136 (1)	0.177** (2.21)
+1 SD above the mean	0.379** (2.32)	0.509*** (2.97)	0.459*** (3.18)

The coefficients are presented with t-statistics computed from robust standard errors in parentheses. Key findings are denoted with significance levels: *** (1%), ** (5%), and * (10%). The marginal effects provide insights into how the interaction between TypePPP10 and specific environmental characteristics influences the outcome under different scenarios.

approaching the other project characteristics adopt the value of 0. Besides, when *DirectNeg*, *DirectGovSupport*, *IndirectGovSupport*, and *Unsolicited* dummy variables adopt the value of 1, the effect of TypePPP10 on the volume of private investment becomes non-significant. Table 8 shows a complementary effect between TypePPP10 and the different factors of the environment. Thus, when the project is performed in host countries one standard deviation above the mean in terms of economic development, institutional stability, and presence of renewable energy, the positive impact on the volume of private investment from promoting PPPs in which the private investor takes more responsibilities is greater.

The analyses are also repeated excluding management and lease contracts, as well as all interacting models, centring the mean with respect to the corresponding variables per year. The results obtained align with the previous findings. For reasons of space, they have not been included in the paper but are available upon request from the authors.

All these results together suggest that the optimal conditions to attract private investment to renewable energy PPPs occur when more project responsibilities are transferred to the private partner and a project host country is more stable in terms of economic, institutional, and sectorial conditions. Other project characteristics that positively impact on the volume of private investment compete with the transference of project risks to the private partner. For example, a direct negotiation method makes it less necessary to promote PPP schemes in which private partner assumes more project responsibilities to attract private money to renewable energy projects.

5. Conclusions

The negative consequences of global warming urge us to take measures to halt the rising temperatures. These negative consequences can especially jeopardize developing countries due to their economic, social, and geographical features. The promotion of renewable energies in these countries emerges as a very powerful tool to spur the transition towards a low-carbonized economic model that contributes to halt these negative effects. In fact, this is explicitly established in target 7b of the SDGs. In this framework, PPPs are key to fostering the development of renewable energy projects in developing countries.

In this research, we have focused on two fundamentals of the PPP: the attraction of private investment and the project risk allocation strategies. We obtain empirical evidence showing that the promotion of PPP types in which the public sector transfers more project responsibilities to the private sector emerges as a key driver to attract more private investment to renewable energy projects. These contractual forms entail more residual control rights over the assets involved in the project for the private contractor, which improves the conditions in which the private company can perform the project, broadens the scope of activities in which the private partner can be involved, and consequently enhances opportunities to do business and make a profit.

We have identified other project characteristics that governments should consider if they want to attract private investment. More concretely, we have found that awarding methods based on direct negotiation, the existence of direct and indirect government support programmes, the support of development banks such as the World Bank, and projects being initiated in the private sector are positively related to a larger volume of private investment in renewable energy PPPs. All these features are related to project characteristics that allow private investors to achieve advantages in different project phases that encourage their involvement in PPPs. Moreover, the characteristics of the environment where the project is performed impact the volume of private investment. Projects performed in sounder economic and more stable institutional environments and in countries where renewable energies are more developed attract more resources from the private sector. These results are not surprising since these environmental features are related to lower uncertainty faced by private contractors, leading to lower transaction costs and more incentives to engage in PPP projects.

To shed additional light, we have explored the existence of substitution and complementary effects between the project risk allocation strategies and the other factors impacting the volume of private investment in renewable energy projects. The results achieved reveal several substitution effects between giving more responsibilities to the private partner and some project characteristics that positively impact the attraction of private investment. More concretely, transferring more responsibilities to the private partner is more necessary to attract private investment when the awarding method is not based on direct negotiation, there is not a local sponsor in the project, there are no direct government support programmes or the support of a development institution, and when the project is initiated in the public sector. Furthermore, the positive effect on private investment attraction of giving more responsibilities to the private sector is more intense when the project is performed in an environment that is friendlier to renewable energies.

The primary contribution of this work in comparison to previous research lies in three distinctly different and previously unexplored aspects. Firstly, in contrast to earlier studies that presented evidence for some of the hypotheses in relation to the weight of private investment compared to public investment (Basílio, 2017; Wang et al., 2019a, 2019b; Fleta-Asín and Muñoz, 2021), our study focuses on the investment volume per se. Thus, a private investor might have a significant role in a project, but the project may not have substantial volume. Here, we find evidence that various factors align in the same manner in both relative participation and volume.

The second distinctive aspect is the inclusion of project and contextual factors at the country level, not considered in previous research (Wang et al., 2019a, 2019b; Fleta-Asín and Muñoz, 2021). This includes the productive capacity of each project and the friendly or socially accepted context for renewable energy projects in the host countries.

The third unprecedented aspect is the incorporation of interaction effects involving seven project factors (direct negotiation, local sponsor, direct and indirect government support, multilateral development banks, World Bank, and unsolicited projects) with their own contract risk level. This element goes beyond, enhances, and sets itself apart from previous studies that only explore interaction effects related to the attraction of private investor weight when utilizing MDBs in favourable economic and institutional environments (Fleta-Asín and Muñoz, 2021); interaction effects involving contract risk and the institutional environment (Wang et al., 2019a); interaction effects between direct government support and the institutional environment (Wang et al., 2019b); or interaction effects between MDBs and other factors in the host country where no significant relationships were identified (Basílio, 2023).

The research results carry significant implications for both policymakers and industry stakeholders in the renewable energy sector. The study not only reaffirms certain patterns observed in previous empirical research, but also unveils nuanced insights into the factors influencing private investment in projects concerning renewable energies. These results provide valuable guidance for policymakers in crafting effective strategies to incentivize private investment in renewable energy projects. Industry practitioners can leverage these insights to make informed decisions, considering the influence of risk allocation strategies, government support, and project characteristics on investment volumes. As the global push towards sustainable energy intensifies, the implications drawn from this research offer actionable intelligence to navigate the complex landscape of renewable energy financing, ultimately contributing to accelerate the transition to cleaner and more sustainable energy sources.

Although all these results are of interest to public authorities in developing countries seeking the attraction of private investment to promote renewable energy projects, the paper suffers from certain limitations that constitute avenues for further research. Thus, we focus on the attraction of private investment to renewable energy projects, but some of the factors attracting this private investment could negatively impact the performance of the project. For example, a direct negotiation method or projects initiated in the private sector are factors useful to attract the interest of private investment but could negatively impact the performance of the project, from other stakeholders' perspectives, due to the lack of transparency and competition associated with these features. It could be very interesting to analyse which factors determine the performance of renewable energy PPPs from different stakeholders' points of view. Furthermore, for data availability reasons, our database lacks some private companies' characteristics that could be useful to explain their willingness to invest in renewable energy projects. Further research should consider such information. Finally, we focus on developing countries, but it could be interesting to analyse the factors attracting private investment in projects performed in developed countries where the institutional characteristics are different.

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Declaration of generative AI in scientific writing

None.

CRediT authorship contribution statement

Jorge Fleta-Asín: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Fernando Muñoz:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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.

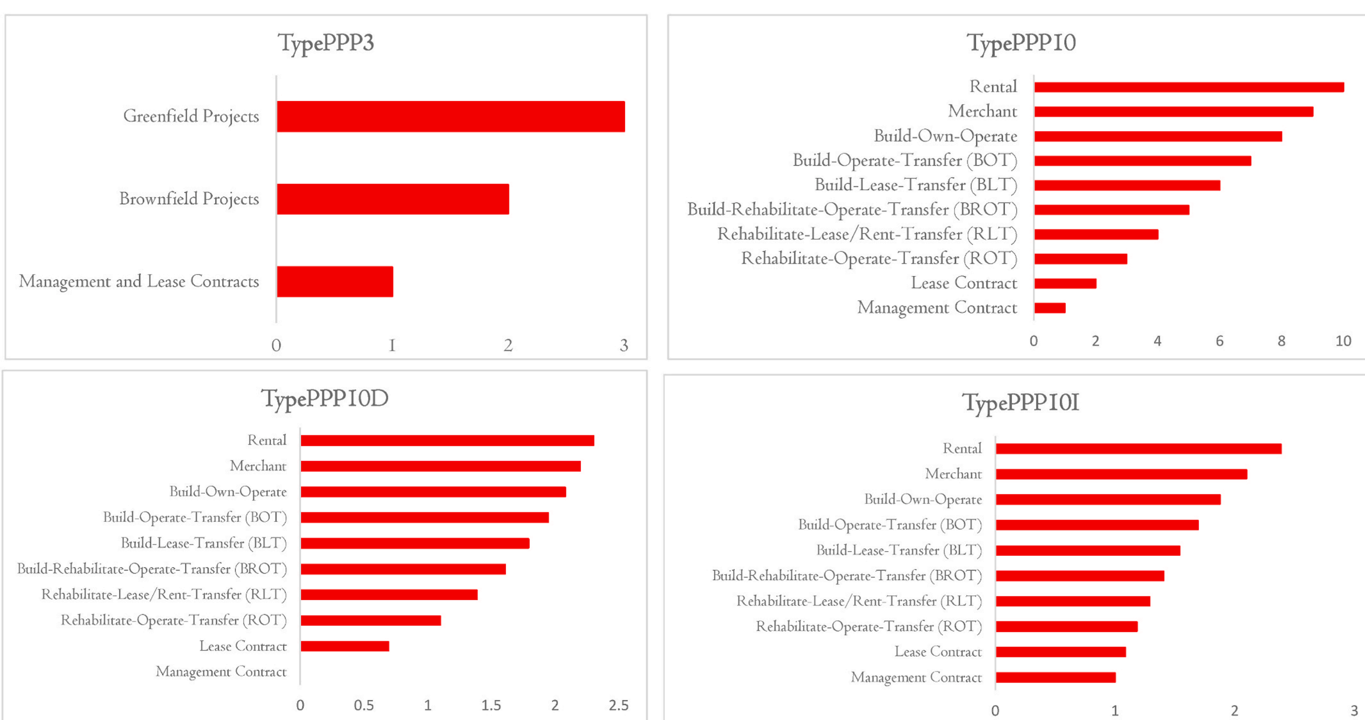
None.

Data availability

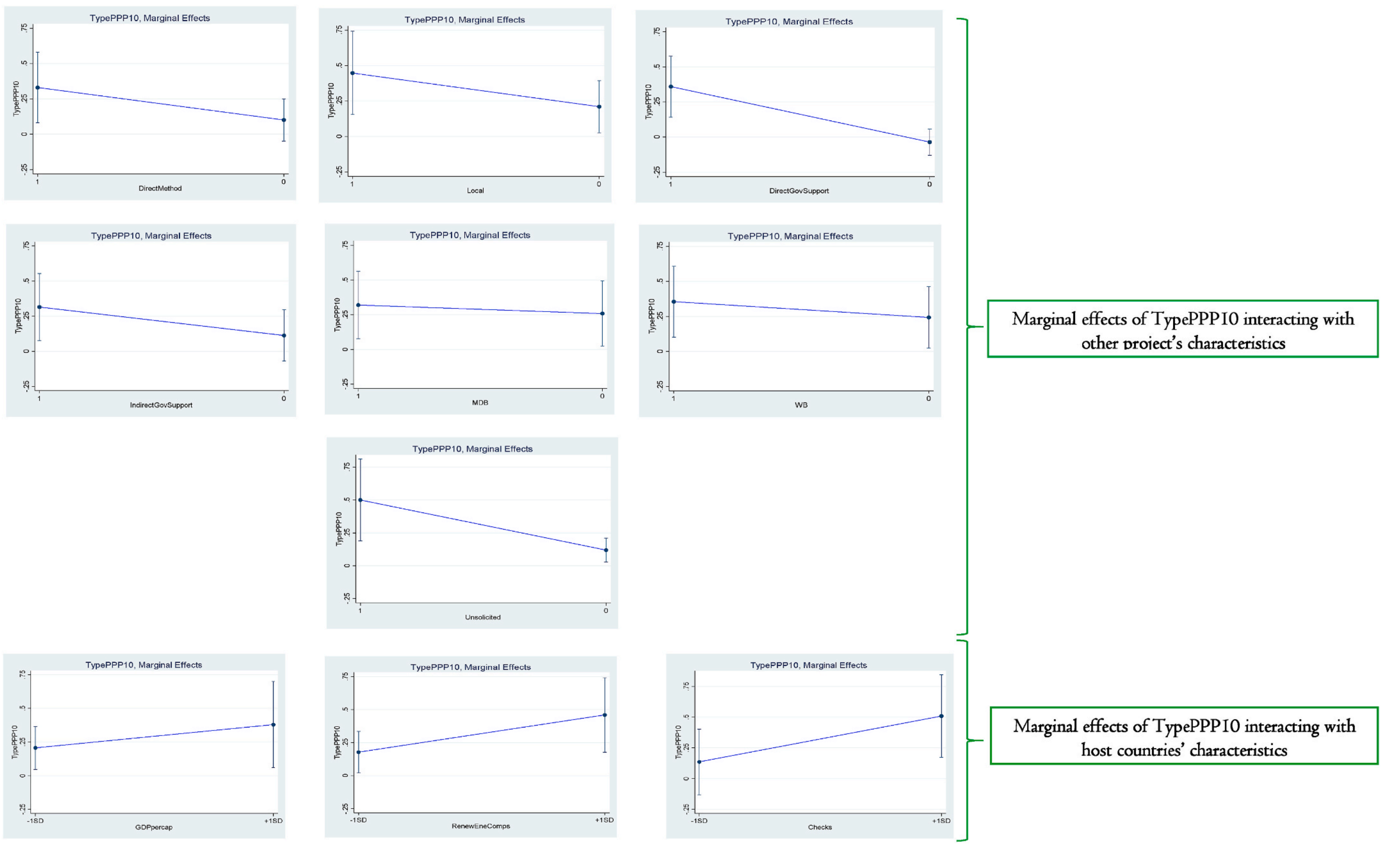
Requests for data availability will be considered by the authors.

Appendix 1

TypePPP3 adopts values in the range 1–3 being: (1) Management and Lease Contracts; (2) Brownfield Projects; (3) Greenfield Projects. TypePPP10 adopts values in the range 1–10 being: (I) Management Contract; (2) Lease Contract; (3) Rehabilitate-Operate-Transfer (ROT); (4) Rehabilitate-Lease/Rent-Transfer (RLT); (5) Build-Rehabilitate-Operate-Transfer (BROT); (6) Build-Lease-Transfer (BLT); (7) Build-Operate-Transfer (BOT); (8) Build-Own-Operate; (9) Merchant; (10) Rental. Wang et al. (2019a) explain the risk taken by the private partner in each PPP contract. Thus, in Management and Lease contracts (1/1–2) private partner only takes the responsibilities of operating and maintaining an existing asset over a short time (3–5 years) and does not have the ownership; in Brownfield contracts (2/3–5) private investors do not own the asset but assume the operation and maintenance risks for a long period (20–30 years); in Greenfield contracts (3/6–10) private investors have the ownership of assets over a long period (20–30 years) being responsible of funding, designing, building, operational and maintenance risks.



Appendix 1.



Appendix 2. Marginal effects from interacting TypePPP10 with the other factors considered across research hypotheses.

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