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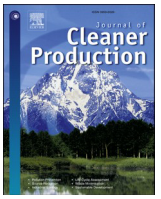

Review

Public-private partnerships for low-carbon, climate-resilient infrastructure: Insights from the literature

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ABSTRACT

Public–private partnerships (PPPs) are increasingly being utilized worldwide as a means of providing climate mitigation and adaptation interventions, including low-carbon, climate-resilient (LCCR) infrastructure. To explore LCCR PPPs in more depth, we conduct a systematic literature review of articles published in peer-reviewed, academic journals between 1990 and 2023, matched with a snowballing search approach. Our analysis is specifically focused on the reasons for public and private involvement in PPPs that solve climate-related problems and the main features influencing the outcomes of these projects. Our findings indicate that public authorities opt for PPPs in LCCR infrastructure projects due to budgetary constraints and the imperative for innovation. Private sector participation is driven by considerations such as profitability, risk mitigation, and favourable policy frameworks. Relative to more traditional PPP models, LCCR partnerships adopt more creative schemes, involve a larger number of stakeholders, display different risk allocations, and pay more attention to social acceptance. Moreover, their outcome and eventual success are more keenly measured in terms of social acceptance, transparency, and their relevance to citizens and social organizations. Future work should assess the overall efficacy of PPPs in delivering climate mitigation and adaptation interventions, especially emission reductions. Additionally, greater attention should be directed towards examining the replicability of case studies. Rather than relying on criteria established in the extant literature, emphasis should also be placed on climate objectives.

1. Introduction

New investment needs are growing in response to climate change. Achieving the 1.5 °C target by 2050 necessitates a cumulative investment of USD $150 trillion, or roughly over USD $5 trillion annually (IRENA, 2023). Despite record-high global investments in 2022 across all energy transition technologies totalling USD $1.3 trillion, annual investment must increase more than fourfold to stay on the 1.5 °C pathway (IRENA, 2023). In Europe, to achieve a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 levels, additional investment of approximately €336 billion per year is needed in the energy system compared to expenditures between 2011-2020.[1]

The sheer size of climate-related investment required to accelerate the low-carbon transition is staggering and there have been repeated calls for large-scale action across multiple sectors and their associated infrastructure to enhance resource and energy efficiency (i.e., mitigation actions). At the same time, the effects of climate change are already apparent in events and heightened risks associated with fluctuating precipitation levels, heatwaves, droughts, floods, and storm surges. These circumstances necessitate infrastructure adaptation to reduce vulnerability and increase resilience to the ravages of climate change. The term low carbon climate resilient (LCCR) infrastructure is usually

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[1] https://investeu.europa.eu/contribution-green-deal-and-just-transition-scheme_en.

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Table 1
Essential elements of the systematic review.

1. Topic Drivers and critical features of LCCR PPPs
2. Research questions - What are the primary motivations and incentives driving public sector engagement in LCCR PPPs? ? - What factors influence private sector participation in LCCR PPPs, and how do these factors vary across different sectors? - What critical success factors and challenges affect the implementation and management of LCCR PPPs?
3. Keywords for search strings TS=((“Public private partnership*” OR PPPs OR “Private finance initiative*” OR PFI* OR “Public private alliance*”OR “Build Operate Transfer” OR “BOT” OR “Build Transfer” OR “BT” OR “Build Own Operate Transfer” OR “BOOT” OR “Build Own Operate” OR “BOO”) AND (“climate change” OR “climate change partnership*” OR “climate finance*” OR “climate resilience” OR “climate-resilient” OR “adaptation investment*” OR “costal adaptation*” OR “mitigation investment*” OR “energy efficiency gap” OR “adaptation gap” OR “land use” OR “renewable opport*” OR water OR “climate proof” OR “low carbon*” OR “low-carbon*” “protection of ecosystem*” OR “ecosystem*” OR “disaster risk*” OR “adaptation” OR “CO2 emission*” OR “climate solution*” OR “LCCR”OR″climate objective*”) AND (“policy response*”OR “cost*” OR “contingent opportuni*” OR “implicit pportuni*” OR “mobilize capital*” OR “financial gap*” OR “value-added” OR “crowding in” OR “off balance sheet” OR “budgetary constraints” OR “local government*” OR “local authorit*” OR “accounting standard*” OR “fiscal deficit*” R “public debt” OR “opportunit*" OR "risk allocation" OR "fiscal implication*" OR "fiscal risk" OR "law suit*" OR "future cost* to government*" OR "Explicit cost"* OR "Implicit contingent liability*" OR "Direct cost*" OR "Indirect cost*" OR "fiscal impact*" OR "fiscal burden" OR "transaction cost*" OR "financing cost*" OR "deferred cost*" OR "additional cost*" OR "unexpected cost*" OR "whole-life cost*"OR "cost overruns" OR "negative impacts" OR "fiscal burden" OR "transparency" OR "risk*"OR”innovative solution*”OR “innovation” OR”expertise” OR “profitability” OR “success” OR “opportunit*”)) AND (SU =(Life Sciences & Biomedicine OR Physical Sciences OR Social Sciences OR Technology))
4. Academic journals database Web of Science
5. Sample criteria Papers published in English in peer-reviewed journals Papers written over the period 1990–2023 Papers from disciplines related to the research questions
6. Inclusion/exclusion criteria Papers covering the following topic: PPPs for climate change mitigation and adaptation projects. In particular: a) articles referring to case studies, interviews, surveys b) articles referring to review to identify further articles.

employed to encompass both mitigation and adaptation infrastructure, mostly in the energy, transport and building sectors.[2]

Many factors impede bridging the gap between required and current levels of LCCR infrastructure investment (Buchner et al., 2019). On the one hand, the governments' ability to allocate sufficient funds to low-carbon projects is restricted by several factors ranging from budget limitations, hesitancy to commit public funds to innovative and advanced technologies, redistributive issues connected to the projects involved, high opportunity costs associated with these investments, political costs of increasing the tax burden, restricted access to debt financing for subnational governments, and finally the unprecedented scale of these investment needs.

On the other hand, private investment tends to flow to more mature and bankable projects rather than to riskier ones while favouring certain LCCR infrastructure (e.g., renewable energy generation) over others (Global Infrastructure Hub, 2022). For example, Bisaro and Hinkel (2018) note private investors express a larger interest in climate mitigation projects rather than climate adaptation projects. The involvement of the private sector in solutions to environmental problems is also not always welcome by scholars and activists, who fear that business could distort the climate discourse to their benefit and perpetuate current structures of the market economy and their climate impact (Hajer, 1995; Blowers, 1998).

Yet, there appears to be a growing need for cooperation between the public and private sector to help accelerate the low carbon transition (Gasparro et al., 2022). The involvement of the private sector has been called on repeatedly at the international level (UNEP, 2016; Paris Agreement, 2015; Glasgow Climate Pact, 2021[3]; COP27[4]; COP 28[5]). OECD also advocates for more private sector involvement in LCCR investments for transport, renewable energy, waste and water management, and public buildings (see, Corfee-Morlot et al., 2012). Among the possible modes of public-private engagement in adaptation and/or mitigation projects, the employment of public-private partnerships (PPPs) is often suggested. PPPs are recognized for their potential to optimize limited public resources by aiding governments in harnessing private capital, expertise, and innovation, consequently unlocking climate finance. They are also viewed as capable of providing a fair distribution of risks among public and private entities, mitigating uncertainties related to climate change through contractual predictability.[6]

PPPs emerged in the early 1990s as a special form of public procurement linking government to the business sector and have since evolved into a complex and sophisticated array of collaborative

[2] LCCR infrastructure encompass projects aimed at either reducing greenhouse gas emissions (such as implementing low- or zero-emission technologies or fostering clean energy generation and conversion) or facilitating adaptation to climate change (such as projects in water management or urban planning). Investments in greening infrastructure can target the refurbishment of existing physical infrastructure, known as "brownfield" investments, such as upgrading power plants or implementing energy efficiency initiatives. Alternatively, they can be allocated to constructing new infrastructure, referred to as "greenfield" investments, such as renewable energy projects or the development of public transportation systems (see, e.g. Kennedy and Corfee-Morlot, 2012; Corfee--Morlot et al., 2012).

[3] https://unfccc.int/sites/default/files/resource/cma2021_10_add1_adv.pdf.

[4] https://unfccc.int/cop27.

[5] https://unfccc.int/event/climate-smart-public-private-partnerships-ppps-building-low-carbon-and-resilient-infrastructure-in#:~:text=PPPs%20can%20help%20maximize%20limited, Sustainable%20Development%20Goals%20(SDGs).

[6] With the aim of achieving this, the World Bank launched its Climate Toolkits for Infrastructure PPPs (CTIP3) in June 2023, to provide guidance on integrating climate mitigation and adaptation strategies into early PPP advisory processes and structuring in emerging markets and developing economies. To complement the overarching CTIP3 designed for multi-sector application, five sector-specific toolkits have been designed (Energy, Transport, Water and Sanitation and Digital/ICT). For more details, see: https://www.worldbank.org/en/events/2023/05/19/climate-toolkits-for-infrastructure-ppps-event.

governance mechanisms to build and operate infrastructures services (Casady et al., 2020; Hodge and Greve, 2010). Even so, the term PPP can also be used to describe less formal or structured partnerships between the public and private sectors, like special forms of collaboration (Osborne and Murray, 2000; Bjärstig, 2017).

The role of PPPs in climate-oriented projects has been limited so far. In 2017–18, only a small share (3%) of publicly sourced, climate investment flows can be clearly referred to as PPPs, and, equally, only 3% of private finance has flowed into PPPs (Buchner et al., 2019). Yet other less traditional forms of PPPs—e.g., those for urban regeneration projects—have been shown to contribute to climate change adaptation and/or mitigation by promoting more energy efficiency in public transport and buildings, reducing carbon emissions, or increasing building resilience (Harman et al., 2015; see also Li et al., 2022).

The primary objective of this research is to scrutinize, through a systemic review, the existing empirical evidence concerning climate-related PPPs. This emerging topic is notably underexplored, as highlighted by Narbaev (2022). Only few reviews have explored the relationships between PPPs and climate adaptation and mitigation (Tompkins and Eakin, 2012). Schneider (2014) reviews the literature on business and public management and analyses the assignment of responsibilities for climate change adaptation by private sectors providers of critical infrastructure. Endo et al. (2022) perform a systematic review on the enabling factors for sustainable infrastructure—a concept that encompasses projects aimed at social, economic, and environmental targets, including climate mitigation and/or adaptation—and find that PPPs are the most mentioned method of finance for all connotations of sustainability, while multilateral finance tend to focus on climate change. These prior reviews confirm the still ancillary role of PPPs with respect to mitigation and/or adaptation interventions. The aim of this study is to identify the drivers and critical features of LCCR PPPs. In particular, this review focuses on three main research questions.

R1. What are the primary motivations and incentives driving public sector engagement in LCCR PPPs?

This question seeks to identify the key factors that encourage public authorities to choose PPPs for LCCR projects. It includes financial, technological, economic and environmental motivations.

R2. What factors influence private sector participation in LCCR PPPs, and how do these factors vary across different sectors (e.g., energy, transport, buildings)?

This question explores the determinants that attract private investors to participate in LCCR PPPs. It also acknowledges sectoral differences in these drivers.

R3. What critical factors and challenges affect the implementation and management of LCCR PPPs?

This question focuses on identifying the essential elements that contribute to the success or failure of LCCR PPPs, including risk management, governance structures, financial arrangements, and stakeholder engagement.

We do not exclusively focus on physical infrastructure, as PPPs for climate adaptation and mitigation also include interventions like street lighting renovation. The term “infrastructure” is used broadly to encompass many types of construction projects, from public buildings (e.g., schools, courthouses, etc.) and transport infrastructure (e.g., roads, bridges, airports, railways, etc.) to energy infrastructure (e.g., renewable energy) or adaptation investments (e.g., coastal protection).

To ensure this research was both thorough and context-sensitive, we employed a systematic review methodology matched with a snowballing search approach. The systematic literature review covered the Web of Science database and includes studies from the social sciences, economics, public administration, accounting, finance, health, engineering, business, and management disciplines. Reports and working papers from international institutions such as the International Monetary Fund, World Bank, and European Investment Bank, as well as other review articles (i.e., Bel and Fageda, 2007; Cui et al., 2018; Bao et al., 2018), were used as background material. Mendely and Nvivo were used to collect the papers and analyse the articles respectively.

The rest of this paper is organized as follows: Section 2 outlines the use of PPPs for climate change purposes from a theoretical perspective. Section 3 describes the methodology and data collection. Section 4 presents and discusses the results. Finally, Section 5 concludes and offers additional recommendations for future research.

2. PPPs for climate mitigation and adaptation

As a procurement model, PPPs are versatile contracts employed in the development and management of diverse infrastructure projects, encompassing both economic infrastructure (roads, bridges, telecommunications, and power), and social infrastructure (including schools, hospitals, and housing). In these long-term contracts between a private party and governmental agency, the private party bears significant risk and management responsibility (Casady and Geddes, 2019; Bennett and Iossa, 2006). Over time, PPPs have evolved in scope and application, seeing increasing utilization in new remits with participation from non-state collaborators (cross-sectors partnerships[7]), especially when initiatives are environmentally impactful (Forsyth, 2005a) and face high levels of resistance from residents, local governments, and outside interest groups.

One of the main features of PPPs is their incorporation of various facets of a project, encompassing design, construction, financing, and operations, and they take different forms depending on the tasks performed by the private partner, ranging from Design, Build, and Finance (DBF) contracts to more comprehensive long-term concessions. The allocation of risks involved in a PPP project—in particular, the construction and demand risks—is a fundamental feature that determines their sustainability, efficiency gains, and the incentives of the parties to provide appropriate services (Iossa et al., 2014).[8]

Governments have traditionally embraced PPPs with key motivations centered on enhancing the efficiency of public service delivery, transferring risks to the private sector, and alleviating budget and borrowing constraints by leveraging private sector funds (Mühlenkamp, 2014; Engel et al., 2020; Carbonara and Pellegrino, 2014). However, public demand for PPP is often influenced by political bias because PPPs can serve the specific interests of public decision-makers (politicians and bureaucrats) better than other management tools. Especially in presence of financial restrictions or limits to debt/tax increases, PPPs allow governments to move activities ‘off the books’ (Bennett, 2004) and offer them more leeway to please their constituencies and extract political rents. Moreover, public administrations wield influence in determining the specific design, procedures, and implementation of the partnerships. They can also utilize PPPs to preserve and assert their influence (Gawel, 2017)[9]. Finally, entrusting private partners with responsibilities

[7] The same initiatives have been called with other names such as ‘civic environmentalism,’ ‘cooperative environmental governance,’ or ‘pro-poor public–private partnerships’ (Forsyth, 2005b).

[8] In the spirit of Public Choice theory, Karsten (2019) interprets governance issues in PPPs as stemming from low-cost decisions made by public decision-makers, as defined by Kirchgaessner (1992). According to his interpretation, the selection and execution of PPPs are deemed significant for local jurisdictions rather than for the decision-makers themselves, resulting in limited incentives for contract monitoring.

[9] Although other digital databases are available, Web of Science was chosen for its comprehensiveness and scientific robustness. It has also been widely used in previous PPP literature reviews (Petersen; 2019; Cui et al., 2018; Neto et al., 2016; Torchia et al., 2015).

traditionally within the purview of public authorities raises concerns related to political accountability, sovereignty, and democratic oversight (Gawel, 2017).

Issues of efficiency, effectiveness, and Value for Money (VfM) are also pivotal motivations for PPP relative to alternative approaches. However, despite the increasingly expansive usage of PPPs, the empirical evidence regarding their benefits is not clear. The performance of PPPs continues to be a subject of debate, given the challenges in delivering public benefits due to inherent complexities involving numerous actors, uncertainty, limited public sector capacity, contractual difficulties, and deficiencies in project design or institutional arrangements (Casady et al., 2020; Casady, 2021, 2024). In certain instances, the inappropriate design of risk allocation results in monopolistic conditions, and excessive guarantees, returns, and rents for private contractors (Vecchi et al., 2010). The consequences ultimately fall on public partners. Indeed, the long-term nature of these contracts may have immediate limited budgetary implications for initiating governments, but they may cause large sudden outlays for the public sector and restrict the fiscal flexibility of future governments in the medium/long term, reducing their capacity to absorb fiscal shocks (Aslan and Duarte, 2014).

In the context of climate mitigation and adaptation actions, which typically require high upfront costs, long-term horizons, and non-excludable benefits, PPPs are still scarcely employed, but some studies support them as an alternative to traditional public procurement. For instance, Agrawala and Fankhauser (2008) suggest that PPPs should be used when governments have limited budget resources, provided that careful cost-benefit analyses are performed and fiscal sustainability conditions are considered. The lack of resources and the limits to borrowing or collecting taxes on residents create barriers also for sub-national government intervention in LCCR infrastructure, thereby increasing the attractiveness of PPPs.

Moreover, PPPs have proven to be valuable in controlling project outcomes, coping with the costs of project preparation, and overcoming the limited capacity of many public actors to generate revenues from LCCR investments and recoup their investments (Bisaro and Hinkel, 2018)—e.g., by selling the land whose value has increased thanks to climate adaptation investments.

Buso and Stenger (2018) note that PPPs could be useful to enhance public sector participation in climate-related investments, given the high levels of future uncertainty connected to climate change evolution and impacts. They claim that PPPs perform better than public subsidies in terms of welfare, investment, and effort, but that these results are conditioned on a series of factors, including well-balanced bargaining power between the public and private actors as well as low costs and the appropriate timing of negotiation procedures. Kennedy and Corfee-Morlot (2012) add that, given the additional risks and complexity that may occur with some LCCR projects, governments must be cautious in procuring infrastructure services through PPP contracts, especially when new technologies are involved.

Moreover, the usual conditions for PPP success still apply—e.g., sufficient institutional capacity, stable regulatory and legislative environment, and well-designed contracts that ensure appropriate risk sharing and flexibility (OECD, 2008; Casady, 2022). Private actors may also resist participating in PPP projects for various reasons, wait for new research findings, postpone interventions, or cover any outstanding damages through insurance. They may also not necessarily adopt the most advanced low carbon technologies and, instead, rely on less innovative solutions (Koppenjan, 2012). Private sector participation in LCCR-PPPs may be further hindered by country risks, scarce possibilities to raise revenues, and distorted distributions of liabilities between public and private actors that both discourage investors and create moral hazard problems.

Finally, from a general perspective, the involvement of the private sector in mitigation and adaptation interventions raises scepticism and concerns from those who believe it does not always guarantee protection of the public interest (Blowers, 1998), introduces risks that can endanger the attainment of sustainability targets (Hayllar and Wettenhall, 2010), compromises environmental codes and standards to the benefit of private companies (Singleton, 2000), while also not accounting for the interests of the poorer parts of the population.

As observed by Narbaev et al. (2020), academic research on PPP covers different topics across multiple disciplines. Systematic reviews on PPP topics have been performed in the past to provide insights on several issues. They highly differ in methodology, topics examined, and the type of PPP contract considered. Some studies perform only one search round on one/two databases and consider only one discipline (Wang et al., 2018; Torchia et al., 2015), while others perform a review only on manually collected documents (van den Hurk, 2018). Still, others conduct a structured search of articles from different databases and different disciplines (Neto et al., 2016; Cui et al., 2018; Petersen, 2019). Few reviews have explored the relationships between PPPs and climate adaptation and mitigation (Schneider, 2014; Endo et al., 2022), confirming the still limited importance of PPPs with respect to mitigation and/or adaptation interventions.

3. Methodology

In this study, we employ a systematic review methodology matched with a snowballing serach approach. Unlike traditional narrative literature reviews, systematic reviews employ a predetermined approach to locating articles and evaluating the current literature, allowing for data replication or the investigation of specific research questions. More specifically, the procedure is centered on the selection of a keyword combination that forms a search string used to identify publications. This methodology limits selection and analysis bias and attempts to provide a thorough and objective picture of the surveyed literature by relying on precise criteria. Following Phillips and Barker (2021) and Rother (2007), we present the main elements of the review in Table 1, while the selection process is illustrated in Table 2.

The aim of this study is to identify the drivers and the critical features of LCCR PPPs. To the best of our knowledge, no previous studies cover this subject. Through an extensive reading of the literature on climate change and PPPs, we first identified a list of *keywords* to employ for search strings in the Web of Science[10] database. This search yielded 150 articles. Then, we established the following *sample criteria*.

1) Articles published in disciplines relevant to climate change mitigation and adaptation projects;
2) Articles written in English[11] between 1990 to March 2023; and
3) Articles covering all countries and sectors.

We removed editorials and book reviews before continuing our examination by excluding all those articles that did not discuss climate-related PPPs (*exclusion criteria*)—i.e., type of PPPs, time period, etc.

Two researchers conducted the selection of articles independently. In cases of disagreement, the full text was read. The first search ultimately yielded 34 articles congruent with our research topic.

To ensure that we captured all pertinent existing literature, we conducted a snowballing search approach (backward), following Wohlin (2014). In practical terms, we manually examined the references of the 34 articles identified in the first search. The procedure yielded 669 additional articles. After checking for duplicates, books, or previously analysed papers, 65 articles were excluded. Of the remaining 604 articles, only 20 articles were considered relevant for the systematic review. This selection was based on the same sample and exclusion criteria

[10] Most leading scientific and scholarly journals are published in English. Additionally, a large majority of the world's academic Web sites and scientific networks function in English.

[11] The identification of the drivers presented in Table 1 are data driven, based on the information found in the papers.

Table 2
Summary of the systematic review process.

1. Studies identification
•Search on Web of Science database (*n*=150)
2. Removal of duplicates and screening of articles on the basis of title, abstract, and keywords
•Articles not relevant for the research are excluded (*n*=116)
3. Five cycles of references screening
•Cleaned database of articles after each round (*n*=604+445+673+310+109)
4. Articles corresponding to the topic (*n*=34+20+21+11+3+0)
5. Articles used after in-depth reading: 24 (around 100 projects)

previously mentioned. We then proceeded to scrutinize all the references of these 20 articles and found 21 more articles pertinent to the review. This process was repeated for three additional rounds for a total of five review phases. In each round, relevant articles were selected and their references were explored. We stopped sampling references only when the articles appearing in these subsequent searches had already appeared in previous searches. We ended up with 93 articles related to the topic in question, which we gathered in Mendeley. Afterwards, the articles identified were imported and analysed using NVivo's qualitative data analysis software. Relevant articles were chosen based on relevant keywords from NVivo's automatic coding as well as the construction of framework matrices that collected pieces of articles' text referring to the previously mentioned keywords. As a result of this screening, we ended up with articles referring to empirical cases which we examined in depth. Only 24 articles were relevant, covering around 100 projects.

4. Summary findings

All the articles reviewed are presented in table A1, including the project, country of implementation, specific project objectives, methodology used, and objective(s) related to climate change.

4.1. Descriptive analysis of sampled articles

The earliest article reporting case studies on climate change PPPs dates to 2005. After an initial uptick in 2008, only about one paper a year was published between 2011 and 2015, except for 2013. Then, in 2017, there is a sharp increase, totalling six articles (see Fig. 1).

In terms of country coverage, Fig. 2 shows how the sampled articles include case studies spreading over five continents (blue countries). Most of them refer to projects implemented in Europe. Greece and Poland are the countries with the largest number of case studies. Most of the countries feature only one project, except for China (7), India (5), Australia (5), the Philippines (3) and the United States (2).

The use of PPPs in climate adaptation is very limited and quite recent. According to a 2008 OECD report, at that time, no PPP projects existed explicitly providing for climate protection (Fankhauser et al., 2008). In our sample, only five papers refer to climate adaptation while most papers refer to climate mitigation (see table A1, last column and Fig. 3a). Still, the sectors covered by climate mitigation interventions are renewable energy and sustainable urbanization, as illustrated in Fig. 3b.

When examining the authors of the papers, no specialisation is apparent. Except for Forsyth, Zhan, de Jong, Harman, and Taylor, the remaining 55 authors only wrote one paper. Most articles (79%) are then co-authored, but only in two cases (Zhan-de Jong and Harman-Taylor) do two-article collaborations have the strongest link. We now turn to examine the drivers of public and private partners' participation and the main features impacting the outcomes of LCCR PPP projects.

4.2. Drivers of public partner participation in LCCR PPPs

We categorize the primary reasons why public actors opt for PPPs to address LCCR investment into five sub-categories. These categories were generated from NVivo's automatic coding and reflect the most frequent words employed in the world cloud of sampled articles (see figure A.1): financial reasons, technological considerations, externality reduction, risk-sharing, and climate goals (Table 3).[12] Some of them are also drivers of traditional PPPs.

The *financial reasons* encompass the significant high up-front capital cost and the long term returns which characterize LCCR projects. These may conflict with government budget resources, fiscal rules and constraints (*budgetary constraints*), and thus justify the preference for PPPs (Chaurey et al., 2012; de Jong et al., 2010; Cedrick and Long, 2017; De Marco et al., 2016; Kościelniak and Górka, 2016; Haughton and McManus, 2012; Martins et al., 2011; Zhan and de Jong, 2017; Zhang et al., 2018). This seems to be especially true for decentralized governments (Zhan and de Jong, 2018), which are more likely to face high indebtedness and resources constraints, given that in many countries they have limited access to financial markets and must adhere to balanced budget rules[13] while meeting emissions targets and complying

[12] This is especially true as fiscal rules often do not differentiate between current and capital expenses and do not protect public investment.

[13] An exemplary situation is described by Jensen and Dowlatabadi (2018) for British Columbia (Canada), where local authorities are subject to a zero emissions target (or offset payments to the government), a ban on future fossil electricity production capacity, a balanced budget rule, and the prohibition of borrowing.

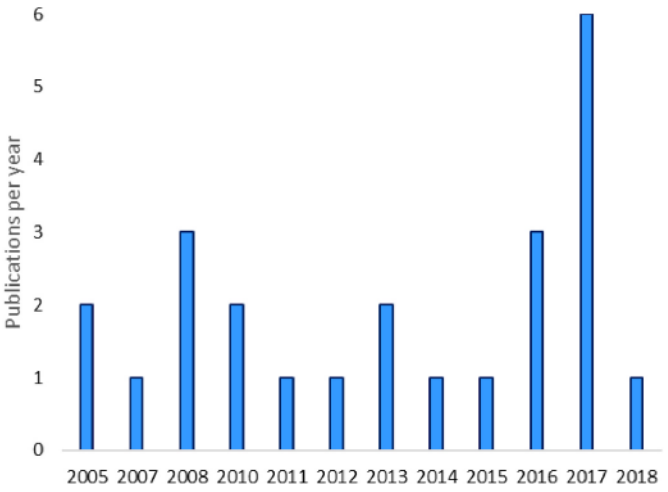

Fig. 1. Sampled articles - Number of publications per year.

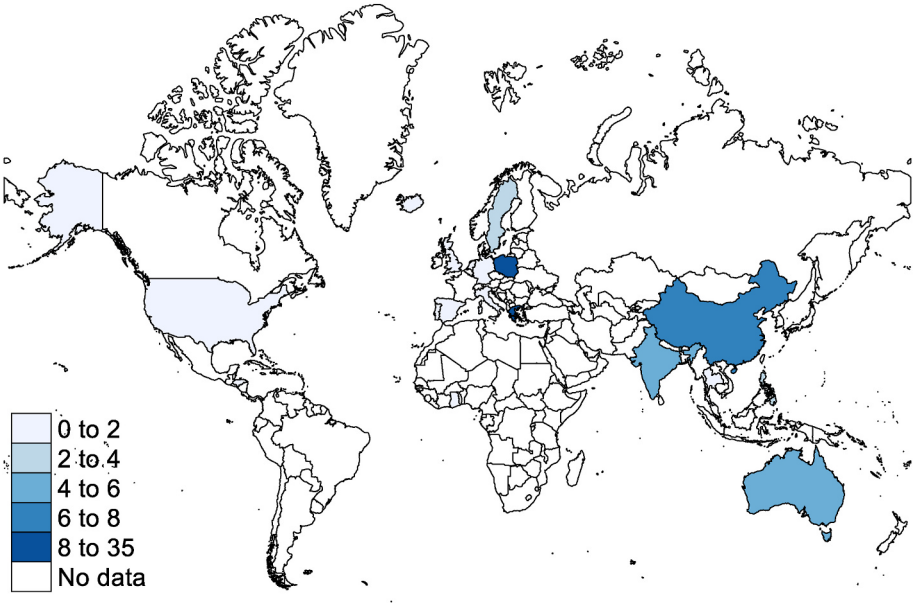

Fig. 2. Sampled articles - Country coverage and number of cases per country.

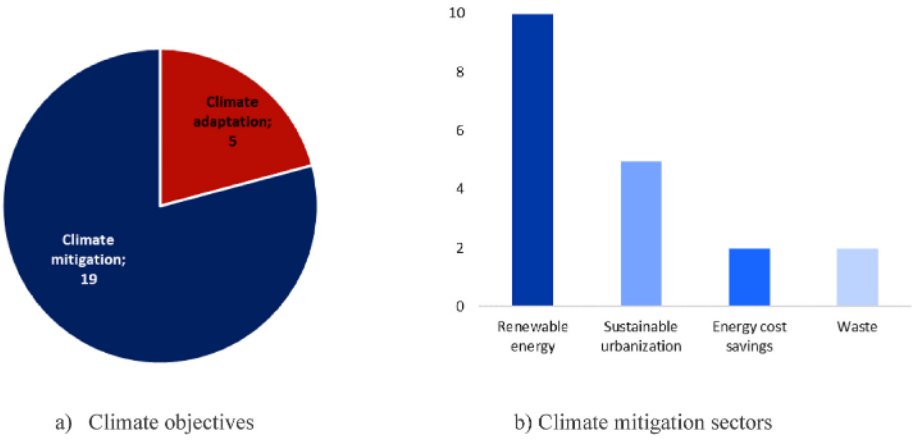

Fig. 3. a and b: Number of articles by climate objectives and climate mitigation sectors.

Table 3
Drivers of public involvement in LCCR PPPs.

	Financial reasons			Governance and technological considerations			Risk sharing	Externalities	Climate objectives
	Budgetary constraints/ limited financial capital	Accounting rules	Cost saving	Technical expertise	Innovative solutions	Public sector capacity			
Cedrick and Long (2017)	X							X	
Chaurey et al. (2012)	X				X	X			
Chmutina et al. (2013)			X			X	X		X
de Jong et al. (2010)	X			X			X	X	
De Marco et al. (2016)	X		X						
Dinica (2008)							X		
Haughton and McManus (2012)	X		X		X		X		
Kristjansdottir and Busch (2019)			X						
Kościelniak and Górka (2016)	X			X					
Kyvelou et al. (2011)	X	X				X			
Martins et al. (2011)	X			X	X				
Tanis and Vergeer (2008)	X		X		X		X		
Zhan and de Jong (2017)	X			X					
Zhan and de Jong (2018)	X			X	X				X
Zhang et al. (2018)	X					X			

with regulations on fossil energy production.[14] The presence of private partners allows local authorities to expand their available resources and grants financial stability to LCCR projects.

The prospect of *cost savings* also motivates public actors to opt for private sector participation in PPPs (Kościelniak and Górka, 2016; Chmutina et al., 2013; Kristjansdottir and Busch, 2019; Tanis and Vergeer, 2008). However, in some cases, the choice of PPPs was based on the distorted perspective that they are a no-cost option for government to build new infrastructure (Haughton and McManus, 2012).

Finally, the choice of PPPs in LCCR investments can be explained by the accounting treatment (*accounting reasons*) they enjoy in some countries, in particular among European Union (EU) member states and for energy efficiency projects (Chmutina et al., 2013). Indeed, there are differences in accounting rules applied to Energy Performance Contracts (EPCs) by Eurostat, the German Statistical Office, and the Länder (Knoll and Senge, 2019). EPCs are a special type of PPP launched to transfer the performance risk of energy efficiency investments from budget-constrained public administration to private partners that guarantee predetermined energy savings.[15] To promote their employment, the EU accounting rules allow for the off-balance sheet registration of EPCs, assuming that sufficient risk is transferred to the private partners.[16] While the Federal Budget Law has repeatedly limited the establishment of EPCs, the Länder have worked out a large variety of accounting treatments that overcome the limits. This conflict recurs also in other countries, and it opposes the search for flexibility in public investments under budgetary constraints and a conservative approach that considers all co-financed investments as public.

Partnerships with the private sector for mitigation/adaption projects are selected not only to leverage funds but also to access specific technological expertise, planning skills, and innovative solutions that are crucial for complex LCCR infrastructure (*governance and technological considerations*) (Chaurey et al., 2012; Dinica, 2008; Haughton and McManus, 2012; Martins et al., 2011). *Capacity* problems of the public sector refer to its insufficient resources and specialized expertise, such as financial and managerial skills, required for the development, management, and operation of infrastructure assets. This deficiency in institutional capacity is highlighted in many instances, particularly when public agencies undertake large and intricate LCCR projects. The issue is especially crucial for local governments and can result in the centralisation of procedures and the uptake of only a limited number of climate PPPs compared to other sectors (Kyvelou et al., 2011; Chmutina et al., 2013).

Technological reasons for choosing PPPs include, first, the *technical expertise* of private companies in cutting-edge technologies (green technologies, renewable energies, big data analytics, cloud computing) that are essential for LCCR projects and that can be better integrated thanks to collaboration with the private sector. *Technological innovation* is also a critical driver in PPPs. Private companies frequently have greater agility and innovation compared to public organizations. Their participation in PPPs has the potential to yield more inventive solutions and enhance project implementation with heightened efficiency and effectiveness. Indeed, PPPs are found to expand the "possibilities for inclusion, networking, information exchange, knowledge transfer and resource mobilisation" (Chen et al., 2013, 141).

Furthermore, many green investments necessitate financial backing to address local and global *externalities*, which private proponents alone lack the capacity to monetize. This results in sub-optimal investment in mitigation and adaptation projects and calls for public sector intervention. Cedrick and Long (2017) observe how environmental (e.g., CO2 emission reduction), social (e.g., jobs in the public sector saved from budget cuts) and economic (e.g., green job creation, electricity cost savings, etc.) externalities are prominent drivers of public sector investment in renewable energy PPP projects. PPPs are preferred also for

[14] EPCs are contracts between a public entity that owns public buildings (e.g., museums, schools, etc.) and an energy service company that commits to investments in energy efficiency measures to obtain a certain reduction in energy consumption levels. The public building owner only needs to pay after the guaranteed energy saving levels are achieved and can be used to finance the investment (Knoll and Senge, 2019).

[15] According to Eurostat accounting rules, PPPs are classified off the government's balance sheet if: (i) the private partner bears the construction risk, or (ii) the private partner bears either availability or demand risk, and (iii) the risks are not incurred by the government through other means.

[16] The distribution of risks should distinguish between controllable risks (to be borne by the agents best able to manage them) and exogenous risks (to be borne by the party best able to diversify or bear it) and account also for moral hazard, adverse selection, and risk-bearing preferences (see Vecchi et al., 2022).

their positive impact on competition, improved transparency, and better legal frameworks, even if not all countries frame these reasons in pro-market terms (de Jong et al., 2010).[17]

Furthermore, efficient *risk allocation*, among public and private actors is a crucial factor driving value for money in PPPs and is also one attractive feature of this type of contract. By transferring some risks to the private sector, public agencies can mitigate their exposure to financial and operational uncertainties and spare them from bearing costs they cannot manage—e.g., cost overruns during construction, delays in construction timelines, and ongoing maintenance of the asset over the long term. Also for LCCR PPPs, one of the most compelling reasons for their adoption is the desire of public authorities to transfer project risks to private partners (de Jong et al., 2010; Haughton and McManus, 2012) or to reduce the risk perceived by private investors (de Jong et al., 2010; Dinica, 2008; Tanis and Vergeer, 2008). Risk reduction is critical during the early stages of dissemination for high-risk mitigation projects (e.g., renewable energy projects) (Gasparro et al., 2022), and the need to provide bankability and attractiveness to the project can induce initial public funding into the total investment (de Marco et al., 2016) or the provision of public guarantees for the project (e.g. wind power, Dinica, 2008). In opting for LCCR PPPs, public authorities sometimes clearly state they want to contribute to the attainment of climate targets (*climate goals*) (Chen et al., 2019; Khan et al., 2020). According to Chmutina et al. (2013) , the Berlin Energy Saving Partnership was expressly designed to contribute to reach Berlin's ambitious climate protection objectives. However, the climate discourse is often not prioritized as the top concern. In some of the reviewed PPPs, public authorities employ selective environmental arguments to help PPPs gain legitimacy, thereby making the funding model of infrastructure take priority over planning based on social or economic principles (Haughton and McManus, 2012). Furthermore, the public perception of climate risk, and consequently the recognition of the necessity for LCCR projects, is not yet robust, as climate-related disasters are still relatively infrequent (Bisaro and Hinkel, 2018). Thus, many projects are geared more toward reactive strategies associated with past climate disasters rather than preparatory actions for future calamities. This is reported in the case of PPPs for urban regeneration, where the relationship with the climate agenda is often not explicit (Taylor and Harman, 2016).

Moreover, national policies on climate change need time to be translated into codes and operational standards at the local level and, in the meanwhile, they do not orientate design decisions. The enhancement of design standards for materials and infrastructure is a dynamic process, evolving over time and is dependent on governments' progressive enhancements of their modelling capabilities. Consequently, while private partners demonstrate a readiness to exceed standards for energy efficiency, there is a reduced inclination, for example, to implement engineering standards beyond those mandated by state planning systems for addressing potential future climate risks. This reluctance stems from concerns about potential lost development opportunities or profitability (Taylor and Harman, 2016)).

4.3. Drivers of private partner participation in LCCR PPP projects

Conventional wisdom dictates that private sector engagement in PPPs is primarily motivated by the pursuit of profit and other business objectives and hindered by high initial investment costs, lengthy investment horizons, unsuitable risk profiles, and distribution and uncertainty surrounding returns. However, the extent of private participation varies, and we aim to delineate the motivations that hold particular significance in adaptation and/or mitigation projects, which are constrained by country-specific barriers, under recognition of investment opportunities, changing environmental policies, and insufficient technological expertise (Corfee-Morlot et al., 2012). As noted by Sullivan et al. (2013), the low carbon agenda may not always align with the needs and interests of private sector investors, even if participation in LCCR can allow private enterprises to meet their corporate social responsibility obligations.[18] Therefore, understanding the private sector's perspective, becomes critical for public authorities (see Table 4). *Profitability*, as expected, is a key driver for private investor participation (Dinica, 2008; Chen et al., 2013; Heldeweget al. 2015; Taylor and Harman, 2016; Cedrick and Long, 2017; Zhan and de Jong, 2017; Zhan and de Jong, 2018; Zhang et al., 2018). However, the uncertainty surrounding LCCR projects and the returns on investments often require that private actors be compensated, either through a government contribution (e.g., subsidies, rebates, public loans and grants, investment/production tax credits) or by redesigning the project (Koppenjan, 2015).

In the aftermath of a disaster, economic motivation aligns with the urgency of disaster relief efforts (Chen et al., 2013). Testimonies from high-level managers in construction companies involved in the aftermath of the 2004 Indian Ocean Tsunami, indicate that, initially, the motivation was primarily "non-instrumental", with profit motivation becoming more prominent as the focus shifted from immediate disaster relief.

Participation in PPPs may also be influenced by future *business opportunities* that feed the market appetite of enterprises (Zhan and de Jong, 2017; Zhang et al., 2018) and by the opportunity to *share risks* (e.g., in urban development projects for climate risk, see Taylor and Harman, 2016). Especially in agriculture where there is low profitability and high risks, private sector lacks incentives to be directly involved in climate change adaptation efforts (Zhang et al., 2018).

However, private participation is also discouraged by long-term cost recovery periods, and public authorities must create positive conditions for business involvement (see e.g., Zhan and de Jong, 2018). Private participation is discouraged when LCCR investment presents large-scale liability risks associated with climate change that are not adequately addressed nor capped (e.g., risk of high sea-level rise for coastal adaptation infrastructure, as in Bisaro and Hinkel, 2018). At the same time, the allocation of risks — "an aspect where PPPs have the greatest potential, but also the highest risk of failure compared to traditional forms of procurement" (Iossa et al., 2014: 459) — should avoid moral hazard issues and poor incentives that arise when private partners are shielded by public guarantees (Vecchi et al., 2022).

The unique forms of some PPPs—such as those in sustainable energy production—impact the distribution of risks among partners, and PPPs should explicitly account for the special position of some partners. For example, in the case of unregulated green gas production examined by Heldeweg et al. (2015), grid operators, despite being private entities (entitled with the construction, management, and maintenance of public energy grids), function as quasi-public authorities and must adhere to norms originating in public law.

Looking at the characteristics of PPP contracts, a certain *degree of flexibility* is needed to avoid lock-in effects in PPP projects and encourage private partners to keep investing in and upgrading LCCR technologies (Koppenjan, 2015). Bisaro and Hinkel (2018) examine the reasons that make a flood risk mitigation PPP project attractive and contract flexibility is key for improving the efficiency of service delivery over time, which is significant when operating costs make up a significant share of the overall project costs.[19] Special forms of flexibility are required in PPPs for climate-related disaster management to deal with highly complex and uncertain situations and adapt the project to new,

[17] Corporate social responsibility is a business model that aims at making companies acknowledge their impact on economic, social, and environmental factors.

[18] In the United Kingdom, PPP contracts are required to consist of over 50% of their present value from operation and maintenance costs.

[19] For example, the long-term coastal defence and management at Pevensey Bay (Tanis and Vergeerer, 2008).

Table 4
Motivations for private investment in PPPs.

Authors	Drivers									
	Profitability	New business opportunities	Non instrumental motivation	Policies promoting renewable energy consumption	Policy continuity	Knowledge development	Pool of resources	Risk reduction	Government subsidies	Corporate social responsibility
Cedrick and Long (2017)	X			X			X	X		
Chen et al. (2013)	X		X							
Dinica (2008)	X	X			X	X	X	X		
Heldeweg et al. (2015)	X			X			X			
Taylor and Harman (2016)	X							X		
Zhan and de Jong (2017)	X	X								X
Zhan and de Jong (2018)	X			X			X			X
Zhang et al. (2018)	X	X					X	X	X	

unforeseen contingencies and information. Chen et al. (2013) notes that PPPs are characterized by a high degree of collaborative strategic decision-making and transfer of operational responsibilities to the private sector, which raises the possibility for opportunistic behaviours. In these circumstances the only solution is provided by long-term, trusting relationships and a structure of incentives which aligns the interests of public and private collaborators.

According to Cedrick and Long (2017), the existence of *policies promoting and securing renewable energy consumption* favours private sector investment in renewable energy PPP projects because they reduce country risks and increase its attractiveness for investors. The creation of an enabling environment that is favourable to PPPs requires strategic intervention and a forward-looking agenda for private investment engagement (Casady, 2021, 2024; Casady et al., 2020). The content and scope of these policies are country-specific and depend on many factors, including the type of energy resources available or the energy capacity required.

Still, *trust in policy continuity*—which creates a low-risk environment—has proved to be more important than high profitability for attracting investors in the wind power sector in Spain, according to Dinica (2008). Institutional investors with long-term liabilities also have an interest in climate-related PPP bonds because of the long-term horizon of these projects (OECD, 2015). However, Bisaro and Hinkel (2018) point to the lack of private sector attraction for some types of PPPs. For example, the size of many costal adaptation projects is too small to match the lower bounds of investment volume (about $30 million) required by institutional investors. Country-level risks related to projects in developing countries also hinder international investment by institutional investors (Casady et al., 2024).

The choice of PPPs by the public sector is usually driven by the expectation of better technology that delivers greater innovation and the modernisation of the public sector. However, *knowledge development* is also a driver for private sector involvement in LCCR PPPs, provided that sufficient reward for innovation efforts is guaranteed.

With reference to the wind-power sector, Dinica (2008) notes that PPP actors are interested in *pooling technical expertise,* strengthening the basis of technology-related information and acquiring knowledge on the location, quality and estimation of wind energy resources, and permitting procedures. Another important driver is the possibility of overcoming the obstacle of limited expertise by potential investors, both in terms of project development and operations.

Lastly, *resource complementarity* played an important role in forming partnerships, especially in overcoming financing obstacles. In Spain, banks were hesitant to provide loans to companies without a track record in electricity generation or experience in wind technology. Dinica (2008, p. 3570) stresses that "PPPs proved excellent policy instruments to generate and sustain private actors' interest in wind power even in the absence of project financing by banks." Indeed, PPPs helped the government mitigate risks perceived by private investors in wind power projects, especially those concerning inadequacies in the design of the Spanish feed-in-tariff instrument. The emergence of new business relations fostered "an investment culture whereby private companies prefer to invest in wind power by means of partnerships with others" (Dinica, 2008, p. 3570), larger projects and, over time, the evolution toward fully private partnership, all while maintaining sustained investment interest in renewable energies.

Among the reasons for private participation in LCCR PPPs, corporate social responsibility is mentioned only in a few studies (Chaurey et al., 2012; Forsyth, 2005a, 2007; Manos et al., 2014). Its relevance is presented in Zhan and de Jong (2017, 2018) with respect to eco-city projects. Indeed, the absence of consideration for social and environmental benefits results in difficulties or the impossibility of finding a balance between societal, communal, and environmental needs, and enhancing value for money or profit-making.

4.4. Features critical for the outcomes of LCCR PPP

The outcome and impact of PPPs is often associated with i) the technical and financial challenges they address; ii) the expectations of private partners for profit and business opportunities; and iii) the expectations of public authorities for service delivery and fulfilling electoral promises. Differing from more conventional infrastructure PPPs, in the case of LCCR partnerships, many scholars stress the role of factors such as their social acceptance, transparency, consultation with stakeholders, relevance to citizens and social organizations (Manos et al., 2014; Zhan and de Jong, 2017, 2018). This is rooted in the novelty and deep transformations involved in the decarbonization process and the actions to cope with climate change, which require enhancing the

credibility of project partners, spurring innovative approaches, increasing political commitment, and generating citizens' support and understanding of the climate agenda.

Certainly, Chaurey et al. (2012) underscore the significance of *assembling all stakeholders*, elucidating their roles, and raising awareness while providing training to each stakeholder at different stages of project implementation. Conversely, Forsyth (2007) observes that the primary causes of LCCR partnership failures are mistrust of new technologies and investing firms, as well as the use of shared forms of partnership, in which different actors share the same role, instead of complementary forms in which the *roles are kept separate*. Project success, instead, involves a clear division of roles in PPPs (Forsyth, 2005a; Fobil et al., 2008) and the structuring of more *deliberative partnerships,* allowing citizens to participate in new infrastructure development, express their local needs, and make them relevant in the decision-making process while increasing collaboration between public, private and civic actors (Fobil et al., 2008). Although public consultations may raise excessive expectations or fuel opposition (Manos et al., 2014), the participation of all stakeholders is critical to devise innovative approaches (Manos et al., 2014) and avoid social conflicts by balancing different interests (Zhan and de Jong, 2018). Political risks (i.e., opposition from residents, local governments, and interest groups) are indeed a significant cause of failure (Kyvelou et al., 2011; Koppenjan, 2015; Haughton and McManus, 2012) and opposition due to inadequate or late consultation or communication with stakeholders can lead to projects delays or cancellations (Manos et al., 2014).

Kristjansdottir and Busch (2019) stress the importance of close *community connections*, the establishment of a *strong intermediary organisation*, and *consistent political support*. Chen et al. (2013) emphasize the importance of intermediary structures with strong ties to all partners in the partnership to close the distance (e.g. spatial, political) between them. According to Zhang et al. (2018), social relations related to the personal relationship the private company had in Wulai village were conductive to the establishment of mutual trust and so favoured the success of the project. Taylor and Harman (2016), on the other hand, highlight informal and regular dialogue as a tool for "alleviating commercial, operational or legal risks that might arise from conflict or poor communication within the partnership" (p. 935).

Among the key features that hold significance for the outcomes of LCCR PPPs, we find the top factors for PPP success that are commonly recognized in the literature are: appropriate risk allocation and sharing, strong private consortiums, political support, public support, transparent and efficient procurement processes, strong commitment by partners, favourable legal frameworks, stable macroeconomic conditions, competitive procurement, clarity of roles and responsibilities among parties, judicious government control, and stable political and social environments (Osei-Kyei and Chan, 2015; Chou and Pramudawardhani, 2015). Studies on LCCR PPPs usually stress the importance of these same factors even if differences can be observed. Indeed, in some instances, the LCCR PPP contract is the first-of-its-kind (i.e., "pathfinder project"[21]) and no previous model exists.

Apart from social capital (i.e., trust, reciprocity, and commitment to the collective), the *institutionalisation of many routines and practises in partnerships*, as well as the *alignment of incentives* between public and private sector partners, are regarded as significant factors in the formation and sustainability of disaster management PPPs (Chen et al., 2013).

As for contractual factors, Forsyth (2007) suggests partnerships should *not* be overly *complex*. Nonetheless, the presence of assurance mechanisms to ensure cooperation, low transaction costs, trust, and transparency are key factors for partnership success, especially in developing countries (Forsyth, 2005b). Zhan and de Jong (2017) consider national *government participation* to be an additional form of insurance against potential failures.

The capacity to choose and *adapt PPPs to specific contexts* is also a critical factor, although some schemes are not free of weaknesses. Standardized contracts for designing, building, financing, operating, and maintaining an infrastructure asset over a concession period—e.g., Build-Operate-Transfer (BOT), Build-Own-Operate-Transfer (BOOT), Design-Build-Finance-Operate-Maintain (DBFOM)—must therefore account for country-specific and LCCR conditions. This can lead to more creative schemes. For example, in the Shenzhen International Low Carbon City, two innovative vehicles were used to help reduce local government expenditures associated with land acquisition as well as funding sustainable urban renewal and the low carbon transition (Zhan and de Jong, 2018). New schemes have also attempted to incorporate sustainability goals into traditional PPPs for urban regeneration (Taylor and Harman, 2016; see also Li et al., 2022) or promote new experimental renewable energy generation. For instance, in the Netherlands' BIONOF case (Heldeweg et al., 2015), the grid's operators played a hybrid role, representing both public and private energy interests. Special forms of PPPs (e.g., Energy Service Companies and EPCs) have also been employed to design, implement, and manage energy-efficiency measures, such as the Berlin Energy Saving Partnership whereby the private partner assumed the performance risk and used its assets as collateral for lenders. However, more traditional project finance schemes can also help reduce risks (De Marco et al., 2016), make projects more bankable, and reduce capital costs.

Dinica (2008) documents the evolution of partnership schemes in Spanish wind power PPPs, which aligned with an increasing trust among investors in renewables, business partners, and public support instruments. The partners who initially invested in one experimental wind project (project-vehicle partnerships) extended their commitments over time, first to multiple wind projects (wind-specialized partnerships), and then to other renewables projects (renewables-specialized partnerships).

The types of *partners involved* in these projects are thus crucial as well. For instance, in the development of agro-energy districts in Greece and Italy, Manos et al. (2014) show how organizing the entire "bio energy chain" for sustainable energy production via PPPs helped agricultural cooperatives provide the land, build the plant, and encouraged their members to provide biomass for the facility. Deliberative cross-sector partnerships, as analysed by Forsyth (2007), also require boundary spanning between organizations (NGOs, non-profit energy consultancies, etc.) as a means of easing relationships between stakeholders and countering resistance to new technologies (Satheesh et al., 2023).

At the same time, some PPPs examined in this review became more fragile due to pitfalls in design, implementation, and market conditions. Competitive procurement and transparency in the awarding of contracts are especially important for selecting qualified private partners, and their absence has undermined the long-term sustainability of PPPs in the past, especially in developing countries (Fobil et al., 2008). As for private sector financial capacity, the relatively small size of many adaptation projects has, so far, been a barrier to investment from institutional investors. As a remedy, Bisaro and Hinkel (2018) propose utilizing development banks to de-risk LCCR infrastructure projects, particularly in developing countries. They also observe that PPPs tend to be more attractive for construction and real estate companies looking to make equity investments as well as for small- and medium-scale adaptation projects in urban and non-urban areas.

Finally, the evaluation of *risks associated with future costs and revenues*, especially their impact and magnitude, remain fundamental to PPP outcomes and success. However, no study in this review mentions the techniques (e.g., risk register, synthetic evaluation approaches, Monte Carlo simulations, etc.) that could have been employed in the cases they examine. The *correct allocation of risks*, instead, turns out to be a critical element for the success of projects examined. For example, in the Portuguese wind energy PPPs analysed by Martins et al. (2011), the private partners bear the risks associated with construction, financing, grid connection, security, and operations and maintenance as well as technological change, service quality, demand, and competition. The public partner keeps the risks related to design, grid failure, environmental

impact, and price volatility. Likewise, in other renewable energy PPPs examined by Cedrick and Long (2017), risks related to design, construction, financing, operations, and maintenance are allocated to the private partners while distribution risks are borne by the public partner. In this case, the transfer of design risk is essential because, in cases where poorly designed infrastructure affects installation or maintenance, private companies bear the additional costs resulting from the damage, and their payment may be impacted due to subpar performance (Cedrick and Jong, 2017).

Energy Service Companies (ESCOs) in PPPs that focus on urban energy efficiency also undertake comparable risks associated with design, financing, implementation, and asset management. Yet, this type of risk allocation is not universal. Different allocations exist for other types LCCR infrastructure. For instance, in Australian urban development PPPs, commercial risks are generally well managed, but private partners leave non-partners (i.e., local authorities, municipal agencies and future residents) to assume the asset maintenance and environmental risks after construction is completed (Taylor and Harman, 2016). This misalignment among partnerships, local authorities' responsibilities, and delays in translating higher-level climate policies into operational standards is found to impede the collaboration necessary for successful adaptation to climate risks. Additional public safeguards have also been observed in urban street lighting renovations (De Marco et al., 2016), as well as other LCCR infrastructure projects where revenue risks are retained by the public sector.

Unforeseen risks should also be afforded special consideration. Tanis and Vergeer (2008) contend that these should not be outsourced to third parties to prevent significant escalation in project and insurance costs. The most cost-effective approach is to share the risk, as exemplified in the coastal defence of Pevensey Bay. In that case, the adoption of innovative solutions led to additional cost savings. Finally, the use of local knowledge also has an effect on project success. For example, in the case of the pumping station in Mangdan, the choice of the power source for the pumping station was made based on the traditional institution of water management within the communities (Zhang et al., 2018).

4.5. Future research directions

We find notable gaps in the current literature that necessitate further exploration in future research. On the public side, the studies predominantly focus on financial, economic, technological, and environmental factors that drive public actors towards LCCR PPPs. However, there is a lack of research addressing the challenges faced by the primary investors in LCCR infrastructure, namely decentralized governments, which frequently contend with high indebtedness and financial resource constraints. Future research should delve into decentralized governance in the context of LCCR PPPs, investigating how these entities navigate financial markets, adhere to budget constraints, and balance emissions targets. Additionally, the existing literature highlights the financial motivations behind public-private collaborations, but future research should aim to unravel the complex interplay of budget constraints, fiscal rules, and climate goals (Cepparulo et al., 2023).

On the private side, while profitability remains a central driver for private sector participation in LCCR PPPs, there is need for more nuanced explorations of the risks and incentives that influence private partners. The current studies acknowledge the importance of factors such as policy continuity and the creation of an enabling environment, but the literature lacks in-depth scrutiny of the repercussions stemming from prolonged periods of cost recovery and the pivotal role played by favourable conditions in stimulating business engagement. Prospective scholarly inquiries should be oriented towards understanding the precise conditions and policy frameworks that serve as catalysts for private sector involvement, particularly considering the prevailing uncertainties and risks attendant to LCCR initiatives. Furthermore, both the dynamic evolution of partnership structures and the typologies of entities entering collaborative ventures require further investigation. This will help us understand how private entities negotiate the multitude of challenges and opportunities inherent in LCCR PPPs.

5. Conclusion

The problems of decarbonization and climate change mitigation/adaptation need polycentric approaches that mix scales of intervention (e.g., local, national, international), tools (e.g., public investment, partnerships, subsidies) and actors (e.g., public authorities, businesses, citizens) (Sovacool, 2011). PPPs are being increasingly utilized to solve issues (e.g., insufficient budgetary resources, access to technology, and flexibility issues) associated with climate-related problems. However, as our systematic review shows, the use of LCCR partnerships is still limited, with a strong prevalence in the renewable energy sector as well as eco and low-carbon city development.

This review shows that there is no single best practice, institutional framework, nor standardized model for PPPs to solve climate-related problems. In many cases, PPPs were chosen to solve problems where no previous model existed. This explains the greater creativity in the schemes adopted, relative to more traditional PPP contracts. Indeed, LCCR PPPs have widened the traditional public-private interface to include other stakeholders, perhaps in the direction of Public-Private-Community Partnerships, as foreshadowed by Koppenjan (2015). The specific type of infrastructure or service provided also guides the selection of the most appropriate type of partnership. Local context, needs, resources, and institutions must be taken into account in the design of country-specific solutions. In time, the long duration of these contracts will provide an opportunity to collect data and determine the efficacy, sustainability, and benefits of the solutions adopted.

Moving forward, codes and standards for PPPs should increasingly include sustainability provisions. However, efforts should be made to gear them towards future developments, rather than relying on reactive and retrospective solutions. Special attention should be paid to technological innovations in these projects that are exposed to risks of obsolescence—a common concern in long-term contracts like PPPs that must adapt to the rapid pace of technological change.

While this paper offers a review of the diversity of PPP schemes around the world related to LCCR interventions, more evidence is needed to assess the potential of PPPs in climate-related investment. COP 28 (2023) puts the private sector at the forefront of the climate agenda. However, further research is needed to assess how PPPs can be extensively and fruitfully utilized to attract capital from long-term investors and deploy technological solutions that meet climate goals, while gaining the support of the communities involved. Risk analyses and risk allocation, public interests and values, and the role of all stakeholders involved will therefore need to be carefully considered. In departing from the classic narratives used to describe PPPs, further research should evaluate the practical effectiveness of PPPs in achieving emissions reductions and broader mitigation goals. Moreover, there should be a heightened focus on assessing the replicability of case studies as well as prioritizing considerations related to climate objectives over other criteria utilized in the existing literature.

CRediT authorship contribution statement

Carter B. Casady: Writing – review & editing, Supervision, Methodology. **Alessandra Cepparulo:** Writing – original draft, Methodology, Conceptualization. **Luisa Giuriato:** Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors have no potential conflicts of interest to disclose.

Data availability

No data was used for the research described in the article.

Annex

Table A1
Main characteristics of the reviewed articles

Article	Project	Objective	Methodology	Objective in relation to climate change
Bjärstig (2017)	39 Natural resource projects in 4 Swedish counties	Management of natural resources	Semi-structured interview	Mitigation/adaptation
Cedrick and Long (2017)	Cases on renewable energy (US, China, Honduras, China, India)	Clean energy production	Case study	Mitigation
Chaurey et al. (2012)	-Lighting a Billion lives (India) -Rajiv Gandhi Grameen Vidyutikaran Yojna (India)-	Off-grid lighting services using renewable energy, Grid extension to rural area	Case study	Mitigation (renewable energy)
Chen et al. (2013)	Natural disaster PPPs (USA)	Building resilience and recovery	Case study	Adaptation
Chmutina et al. (2013)	Berlin Energy Saving Partnership (Germany)	Modernisation of public infrastructure in order to guarantee energy cost savings	Case study	Mitigation (Energy efficiency)
de Jong et al. (2010)	Subway infrastructure (China)	Reduce congestion and emissions	Case study	Mitigation
De Marco et al. (2016)	Street lighting system project in Turin (Italy)	Energy-efficient lighting systems	Interview	Mitigation
Dinica (2008)	Wind power (Spain)	Clean energy production	Interviews and documents	Mitigation
Fobil et al. (2008)	Waste management (Ghana)	Reduce emissions	Case study	Mitigation
Forsyth (2005a)	Waste-to-energy technologies (India and the Philippines)	Clean energy production, reduce water pollution	Interviews and documents	Mitigation
Forsyth (2005b)	Waste management and waste-to-energy technologies (the Philippines and Thailand)	Clean energy production, waste reduction	Case study	Mitigation
Forsyth (2007)	Waste-to-energy technologies (India, the Philippines and Thailand)	Clean energy production	Case study	Mitigation
Haughton and McManus (2012)	Cross CityTunnel (Australia)	Less congestion and lower pollution levels	Case study	Mitigation
Heldeweg et al. (2015)	Biogas grid Noordoost Fryslân (The Netherlands)	Green gas production	Interviews and documents	Mitigation
Kościelniak and Górka (2016)	35 projects in Silesia (Poland)	Green cities	Case study	Mitigation
Kristjansdottir and Busch (2019)	Low carbon transition of Akureyri (Iceland)	Urban transformation process of local carbon flows	Case study	Mitigation
Kyvelou et al. (2011)	29 environmental projects mostly related to waste management (Greece)	Urban sustainability	Case study	Mitigation
Manos et al. (2014)	Agro-Energy Districts in Kilkis Prefecture (Greece) and Umbria (Italy)	Bio-energy production	Interview and documents	Mitigation
Martins et al. (2011)	Wind power plants (Portugal)	Green energy	Case study	Mitigation
Tanis and Vergeer (2008)	Pevensey Bay (UK)	Long term defence coast	Case study	Adaptation
Taylor and Harman (2016)	Four urban development for climate risk projects (Australia)	Climate-adapted urban development	Case study	Adaptation
Zhan and de Jong (2017)	Sino-Singapore Tianjin Eco-City (China)	Emission of GHGs, the greening of urban space, rationalizing the use of resources, and promoting alterations in the energy mix towards renewables	Interviews and documents	Mitigation
Zhan and de Jong (2018)	Shenzhen International Low Carbon City (China)	Sustainable urbanization	Interview and documents	Mitigation
Zhang et al. (2018)	Pumping stations in Mangdan Village and in Wulai (China)	Farmers' adaptation to drought	Interviews	Adaptation

Fig. A.1. 50 most frequent words in the sampled articles.

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