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EXPLORING SYSTEM BOUNDARIES FOR GREEN PUBLIC-PRIVATE PARTNERSHIPS

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Abstract. This study addresses the research gap in understanding the intricate dynamics of public-private partnerships (PPP) in fostering sustainable development by proposing a framework delineating eight system boundaries for green PPP. Through analysis across four cases from BRICS countries, the research illuminates the nuanced and interactive nature of these boundaries. The findings underscore the necessity of recognizing green PPP as complex socio-technical systems. The paper emphasizes the diversity and complexity of green PPP's boundaries and highlights the importance of explicitly delineating them for meaningful comparison across contexts. By clarifying these perspectives, the study contributes to enhancing academic understanding and practical implementation of sustainable development initiatives through PPP.

Keywords: green PPP, system boundary, green practice, sustainable development.

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1. Introduction

Climate change has emerged as a pressing global challenge, prompting a revaluation of policies and strategies across various levels of governance (Baietti, 2013; Pauline & Lema, 2024). Governments and cities increasingly acknowledge the imperative to adopt sustainable and climate-resilient practices to mitigate and adapt to these challenges. However, the financial burden often deters the adoption of such practices, particularly for public sectors reliant solely on public funds (Baietti, 2013). Public-private partnerships (PPP) has been posited as a potential solution, aiming to alleviate fiscal constraints by leveraging private sector expertise and resources to achieve sustainable development goals (SDGs) (Koppenjan, 2015; Shiferaw et al., 2012; Xiang et al., 2022). These partnerships foster multilevel, multidisciplinary interactions, facilitating innovation in local institutions and mechanisms for climate governance (Li, 2020). Given the increasing focus on sustainability and environmental protection, green PPP has garnered substantial attention and support from both academia and industry (Vassileva & Simić, 2023). Compared to traditional PPP, which typically prioritizes infrastructure construction and service provision, green PPP emphasizes the commitment to SDGs (Vassileva, 2022).

The implementation of PPP encounters several challenges, including the lack of professional skills in the public sector (Colverson & Perera, 2012), delays in achieving financial close (Babatunde & Perera, 2017; Kurniawan et al., 2013; Pieters et al., 2014), protracted decision-making processes and bureaucratic processes (Khoza & Rabie, 2021), technical complexities (Hwang & Tan, 2012; Zhang et al., 2011), and failures in demand forecasting and financing (Lee et al., 2022; Sourani & Sohail, 2011). The fundamental issues behind such challenges result from the complexity of PPP. The concept of green PPP, proposed to address the intricate challenges of sustainable development, is regarded as a more complex socio-technical system since it places a heightened emphasis on environmental protection, social responsibility, and sustainable development, often necessitating consideration of a broader array of stakeholders and more advanced technical requirements (Vassileva, 2022). Despite the fact that sustainable development has become a crucial part of the global agenda, and some of the current studies have engaged in a variety of research on PPP in the context of SDGs (Bäckstrand & Kylsäter, 2014; Caloffi et al., 2017), there are still significant knowledge gaps within the realm of PPP, particularly

regarding environmental protection and social responsibility. The theoretical foundations, implementation strategies, and impact evaluation of green PPP were overlooked in the literature, resulting in imperfect policy and project designs in practice, thereby failing to fully utilize the potential of green PPP initiatives (Cheng et al., 2021; Raouf & Al-Ghamdi, 2019; Vassileva, 2022).

The focus of this paper is to develop a conceptual framework to describe a theoretic set of boundaries associated with green PPP. Such a theoretical framework can provide new insights for decision-makers, practitioners and researchers, to better cope with the challenges and opportunities of green PPP projects, to better coordinate and integrate the resources and efforts of various stakeholders and thus improve the efficiency and results of project implementation. Our methodology uses the sequential qualitative mixed-methods design. The core component of semi-structured interviews and local cases explored the boundaries and associated parameters of the green PPP. Then, the supplementary component of international case studies further explored and contextualized the framework within four real-life projects in BRICS countries.

In the next section, we offer a thorough examination of existing literature about green PPP to establish a foundation for our research. Building upon the literature review, a conceptual framework for understanding the system boundaries of green PPP is introduced, which is pivotal for structuring and managing these partnerships within a systemic context. The methodology section describes our methodology to explore and verify the proposed framework. We then elaborate on our results and analysis carried out to test the scientific and universality of this framework. The discussion section interprets the results and situates them within the broader context of green PPP research. Finally, we conclude this work.

2. Literature review

2.1. Definition and characteristics of green PPP

Human languages are primarily constructed through analogies (Hofstadter & Sander, 2013). Conceptual entities such as enterprises, universities, or governments enter into linguistic systems through analogies or metaphors, and the boundaries of concepts endow such conceptual entities with greater vitality. Whether green PPP can become a new generation PPP paradigm as a concept metaphor depends mainly on whether it can possess a theoretical framework defining its boundaries. There is currently limited academic response and no consensus on this issue. Pan (2014) examined the concepts of the system boundaries of zero-carbon buildings and developed a theoretical model covering eight types of boundaries, namely policy timeframe, building lifecycle, geographic, climatic, stakeholder, sector, density, and institutional boundaries. He argues that defining the boundaries of zero carbon buildings is necessary to elaborate concepts and guide research. This raises questions about whether green PPP can find a similar boundary model.

In terms of concept formation and comparison, green PPP is developed based on the PPP concept. Early initiatives, such as the UK's guidance on incorporating environmental considerations into PPP and Private Finance Initiative (PFI) projects in 2002, laid the groundwork for integrating sustainability principles into PPP frameworks (Office of Government Commerce [OGC], 2002; Vassileva & Simić, 2023). Similarly, the United Nations Industrial Development Organization [UNIDO] introduced the term "green industry" and advocated for its adoption to position sustainable industrial development within the context of emerging global sustainable development challenges, further emphasizing the importance of environmental considerations in PPP (UNIDO, 2011). Throughout the conceptual evolution of green PPP, starting from its first proposal in the UK in 2002 to incorporate environmental factors into PPP projects and Private Finance Initiative (PFI) projects, to the subsequent emergence of various metaphorical concepts such as ecological partnerships, green infrastructure partnerships, and green investment partnerships by academia, industry, and policymakers, these metaphors reflect different understandings and applications of the green PPP concept. However, they intersect with multiple conceptual boundaries, all emphasizing the significant role of PPP in promoting pollution prevention, sustainable development, and the green economy (Batista et al., 2021). In this process, scholars have provided different definitions of green PPP due to contextual differences, and a unified definition has yet to be reached.

This paper adopts the definition of green PPP by the Chinese Ministry of Finance (2024): "*PPP projects that support pollution prevention and promoting green low-carbon economic structure in public transportation*, *water supply and drainage*, *ecological construction*, *and environmental protection*, *water conservancy construction*, *renewable energy*, *education*, *science and technology*, *culture*, *pension*, *medical and health care*, *forestry*, *tourism and other fields of green low-carbon economic structure*." This definition highlights the differences between green PPP and other PPP regarding project scope and objectives. Specifically, compared to traditional PPP, this definition emphasizes several key distinctions:

- Specificity of project domains: Green PPP emphasizes projects in environmental protection, sustainable development, and the construction of a green economic structure, covering areas such as pollution prevention and control, public transportation, water supply and drainage, ecological construction, environmental protection, water conservancy construction, and renewable energy. In contrast, traditional PPP projects may involve a wider range of project types, including but not limited to government infrastructure and highway construction.
- Sustainability of objectives: The goals of green PPP are more focused on sustainability, emphasizing the construction of a green low-carbon economic

structure. This means that projects will pay more attention to factors such as environmental protection, resource utilization efficiency, and carbon emission reduction during implementation, to ensure their positive impact on the environment.

- Emphasis on social welfare and public services: The definition also mentions fields such as education, science and technology, culture, elderly care, healthcare, forestry, and tourism. This indicates that green PPP not only focuses on economic benefits but also emphasizes the provision of social welfare and public services, differing from traditional PPP, which tends to prioritize infrastructure construction and commercial projects.

In summary, this definition of Green PPP emphasizes the differences from traditional PPP in project selection, implementation objectives, and social benefits, placing a greater emphasis on promoting sustainable development and environmentally friendly projects.

2.2. Key research themes regarding green PPP

With the increasing global awareness of sustainable development and environmental protection, green PPP has emerged as a widely recognized research area in academia and practice. Guided by the definition of green PPP, as well as distinctions between green PPP and traditional PPP, three key thematic categories have been identified, namely: (1) Sustainable development, (2) Ecosystem services, (3) Climate change adaptation (Ali et al., 2019; Berezin & Ratner, 2019; Filimonova et al., 2023; Kang & Park, 2013; Xu et al., 2022).

In the realm of sustainable development, the existing literature focused on the role of green PPP in promoting SDGs (Cheng et al., 2021; Ning et al., 2023; Zaki & Hegazy, 2023), such as improving building energy efficiency (Cheng et al., 2021). In general, such literature delved into how PPP facilitates sustainable resource utilization and how to adopt modern and efficient technologies and other green innovations to establish a sustainable environment in addressing SDGs (Cheng et al., 2021; Ning et al., 2023; Zaki & Hegazy, 2023).

Ecosystem services have emerged as another critical area of inquiry within green PPP research. The existing literature investigated the contributions of PPP to maintaining ecosystem services in terms of enhancing the resilience of water, sanitation, and hygiene systems to hazards (Johannessen et al., 2014), fostering the digital transformation of publicly owned healthcare organizations (Casprini & Palumbo, 2022), and safeguarding biodiversity and sustainable agriculture (Carillo et al., 2023; Dwyer et al., 2020).

Climate change adaptation predominantly centers on the application of green PPP in the energy sector (Ali et al., 2019; Berezin & Ratner, 2019; Filimonova et al., 2023; Kang & Park, 2013; Xu et al., 2022). Research endeavors encompass innovations and practices in energy management and utilizing green energy sources, such as renewable energy (Xu et al., 2022).

3. Conceptual framework of system boundaries for green PPP

The concept of system boundaries is multifaceted, drawing from various theoretical frameworks, such as open system theory, societal system theory, and dialectical system theory (von Bertalanffy, 1968; Ludu, 2016; Luhmann, 2006; Mulej et al., 2017; Pan et al., 2018). In this study, the concept of system boundaries is applied within a specific context of green PPP, as these projects are inherently complex and heterogeneous span various sectors, involve multiple stakeholders, and operate under diverse regulatory and environmental contexts. This study defines system boundaries in relation to the distinct components or subsystems that collectively shape the overall structure of green PPP. These boundaries are not rigid but are essential for framing a systematic analysis of green PPP. To facilitate a comprehensive understanding, eight types of green PPP boundaries have been developed based on a literature review: sector, stakeholder, procurement model, lifecycle, policy instrument, payment mechanism, operational mode and green practice. These boundaries address key questions of what, how, when, who, and where within the context of green PPP. Each boundary provides a unique perspective, enabling a more nuanced and systematic examination of the various facets of green PPP projects. Without explicitly defining these boundaries, comparing green PPP across different contexts would be akin to "comparing apples to pears". These boundaries thus facilitate clearer, more structured comparisons and analyses, helping to better understand the structure, dynamics, and diverse perspectives that shape green PPP.

3.1. Sector

The sector boundary denotes the initiating sector/ authority and types of the projects. The sector boundary for a specific "green PPP" would depend on the nature of the project and the goals of the partnerships. For example, a green PPP project focused on renewable energy might operate within the energy sector, while one focused on sustainable transportation is mainly in the transportation sector. This paper proposes to apply the sector boundary as a means to indicate the initiating sector/ authority of the project (whether a project is initiated by the public authorities or private sectors) and types of the project (such as ecological construction and environmental protection, transportation, education, forestry, energy and so on) of a project.

3.2. Stakeholder

The stakeholder boundary defines the people and organizations that are affected by green PPP and/or the cooperation process. Stakeholders are modeled as responsible, impacted or interested (El-Gohary et al., 2006; Zhu et al., 2019) or who have a "stake in" or "interest in" the project (Littau et al., 2010). Stakeholder analysis helps to prioritize different stakeholders' short-term and long-term interests and make decisions (Pan, 2014).

3.3. Procurement model

The procurement model boundary denotes the processes governments and public authorities used to select private sector partners for the development and operation of infrastructure or public service projects. The application, selection, and design of procurement models are the core elements of government procurement systems (Pu et al., 2020). The appropriate procurement model reduces the risk of project failure (Carbonara et al., 2016; Estache et al., 2009) and contributes to selecting the best private sectors (Pu et al., 2020) and design solutions (Herweg & Schmidt, 2017). Typically, tendering and negotiation are two major classifications of the procurement model. Different international organizations and countries have expressed various opinions on classifying procurement models. Cao and Wang (2022) divided procurement models into tendering and negotiation.

3.4. Lifecycle

The lifecycle boundary expounds the whole life cycle of green PPP. According to the Ministry of Finance's PPP guidebook, the life cycle of a PPP project includes five stages: identification, preparation, procurement, execution, and transfer (Tan & Zhao, 2021). Green PPPs are essentially PPPs, so it can be considered that the lifecycle of green PPP is consistent with that of other PPP projects.

3.5. Policy tool

The policy instrument boundary expounds various methods, means and implementation mechanisms adopted by the government to meet the public's demand for green PPP. Policy tools are a critical part of policy-making, providing the "means" by which policy "ends" are achieved (Bali et al., 2021). Due to the lack of literature to systematically study the policy tools of green PPP, this paper combines the public product attributes of green PPP and explores the boundaries of its policy tools according to the policy analysis framework of public cultural services. The policy tool can be divided into five types: commanding, incentive, capacity-building, system transformation, and advising.

3.6. Payment mechanism

The payment mechanism boundary is employed to ensure that private sector partners receive adequate returns on their investments. It also helps to ensure the efficient delivery of public infrastructure or services. There are three types of PPP projects based on payment mechanisms, namely, user charges, government payment and viability gap funding (Cui et al., 2018). The conceptual framework is shown in Figure 1.

User charges are fees or payments made by end-users, such as individuals or businesses, for the use of the infrastructure or services provided under the PPP agreement. Viability gap funding is financial support provided by the public sector to the private sector partner to bridge and narrow the gap between the expected revenues (including user charges) and the costs of delivering the infrastructure or services (Deulkar & Shaikh, 2013; Song et al., 2015). Government payment involves direct financial contributions from the public sector to the private sector partner through availability payments (Mahani et al., 2022), performance-based payments (Shang & Abdel Aziz, 2020; Su et al., 2023) and other forms of compensation. Government payments are made to incentivize private sector participation and ensure the delivery of specific public services or infrastructure. They are often used when projects that do not possess the characteristics of "operate", otherwise referred to as the non-operating PPP projects (e.g., urban road and urban renewal) (Morano & Tajani, 2017).

3.7. Operational mode

The operational mode boundary denotes how PPP projects to be operated. The operational mode also defines the roles, responsibilities, and relationships between the public authorities and the private sector entities. Inspired by Cui et al. (2018), this paper concludes common PPP operation modes under different project statuses (Table 1).

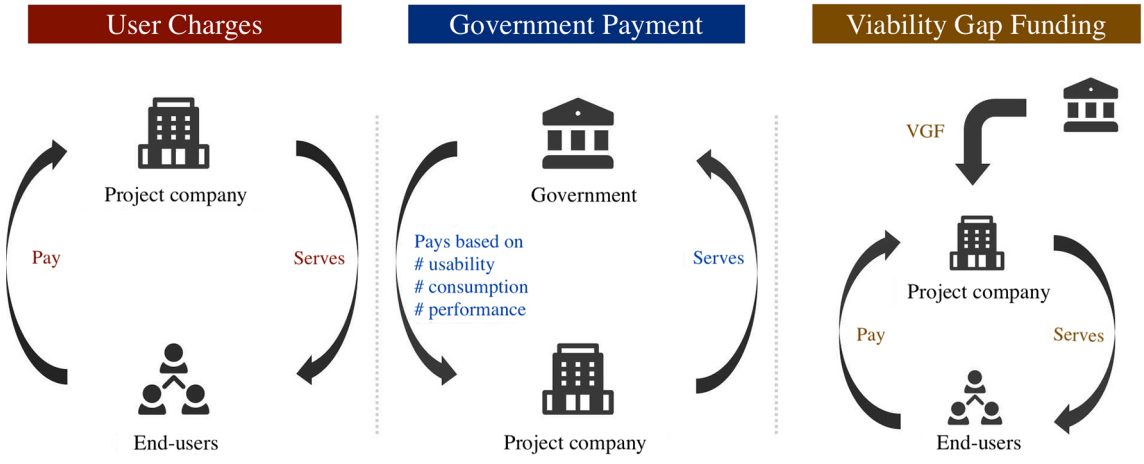


Figure 1. Conceptual framework of three payment mechanisms of green PPP

Table 1. Common PPP operational modes

Project status	Operational modes
New-build (N)	■ Build-Operate-Transfer (BOT) ■ Build-Own-Operate (BOO) ■ Design-Build-Finance-Operate-Transfer (DBFOT) ■ Build-Own-Operate-Transfer (BOOT) ■ Build-Transfer-Operate (BTO) ■ Build-Lease-Operate-Transfer (BLOT) ■ Build-Lease-Maintenance-Transfer (BLMT)
Existing (E)	■ Transfer-Operate-Transfer (TOT) ■ Rehabilitate-Operate-Transfer (ROT) ■ Operations and Maintenance (OM) ■ Management Contract (MC) ■ Operation-Management-Development-Transfer (OMDT) ■ Lease-Operate-Transfer (LOT)
Existing and New-build integrated (E+N)	■ Combination mode, e.g., BOT+TOT, and BOT+ROT

3.8. Green practice

The green practice boundary denotes the green initiatives and practices implemented in PPPs, aiming to achieve environmental and climate goals. Hueskes et al. (2017) argued the necessity of embracing sustainable considerations in PPP implementation and further explored enhancement strategies. Failure to embrace green initiatives and practices in PPP/PFI projects indicates the opportunities to reduce the whole life cycle costs may be missed (Suresh & Akintoye, 2010), Furthermore, PPP contracts may last for several years, and the useful life of the related assets maybe even longer. Failure to incorporate green initiatives and practices in the early stages of a project may have long-term negative impacts (OGC, 2002). By integrating green design, construction and operation practices into PPP projects, energy consumption, carbon emissions and resource utilization efficiency can be reduced, thus reducing the overall cost of the project (Bu et al., 2025; Ning et al., 2023; Tavana et al., 2022). At the same time, this approach can also enhance the social acceptance of the project and enhance the sustainability and long-term benefits of the project (Ning et al., 2023). Therefore, implementing green initiatives and practices not only contributes to achieving environmental protection and climate change mitigation goals, but also provides economic benefits (Tavana et al., 2022).

4. Methodology

4.1. Research design

The sequential qualitative mixed-methods design (Morse, 2010; Morse & Niehaus, 2009) adopted in the exploration is graphically illustrated in Figure 2. The core component (i.e., QUAL) (Morse, 2010) of semi-structured interviews and local cases explored the boundaries and associated parameters of the green PPP. Then, the supplementary component (i.e., qual) (Morse, 2010) of international case studies further explored and contextualized the framework within four real-life projects in BRICS countries. Theorizing in an abductive direction, the QUAL and qual were carried sequentially to explore the system boundaries and associ-

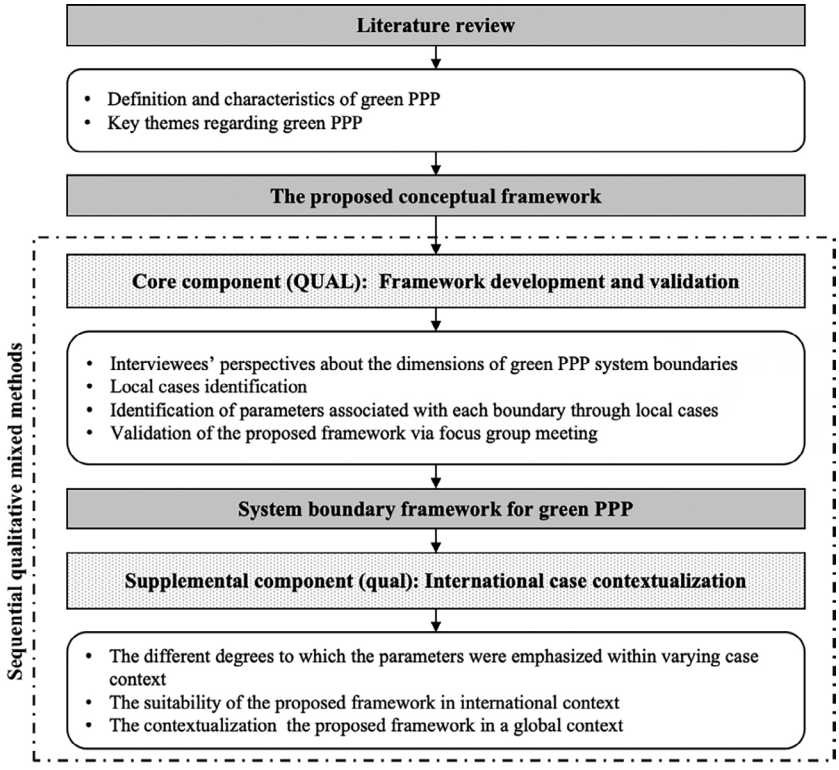


Figure 2. Research roadmap

ated parameters of the proposed framework. The QUAL → qual mixed-methods design sought to form rich descriptions based on concrete empirical evidence and achieve theory development by working towards more abstract parameters and theoretical relationships (Morse, 2010; Ong, 2012; Yin, 2013). The QUAL completed and formed the theoretical base under the local context, that is, green PPP projects in China, while the qual supplemented the QUAL by answering the minor questions that emerged from the QUAL and providing project insights into the international context. Hence, the qual moved the framework from local theoretical development towards international practical implementation.

4.2. Core component (QUAL): framework development and validation

The dimensions of green PPP system boundaries were first explored by literature review and validated by 7 face-to-face semi-structured interviews with carefully selected experts (Table 2). The interviewees included different stakeholders representing public authorities, private sectors, contractors, consultants, and universities. The wide range of interviewees enriched the perspectives and understanding of the dimensions of green PPP boundaries. Most of the interviewees possessed more than 9 years of working experience in the Chinese construction industry and participated in one or more green PPP projects at the time of this research. Each interview lasted approximately 30 minutes and was audio-recorded with prior permission. Following the numerical guidelines to determine the sample size (Sim et al., 2018), the interviews continued until saturation occurred, that is, no new category of dimensions were identified, and limited new information was found through the analysis of the transcripts.

During the interview, the government representatives offered a set of green PPP projects data comprising detailed information on 546 projects in Sichuan Province up to the end of September 2022. Among these, 214 projects were identified as pertaining to the green low-carbon sector. This data served as a valuable reference for further analysis of the parameters of green PPP system boundaries. The raw data of such green PPP projects were structured under eight dimensions outlined before. The structured database (Figure 3) formed the foundation for parameter identification in each system boundary.

Table 2. Profiles of face-to-face semi-structured interviews

No.	Organization	Role	Working experience related to green PPP
1	Public authorities	Senior officer	10 years
2	Public authorities	Senior officer	8 years
3	Private sectors	Senior manager	9 years
4	Contractor	Registered engineer	9 years
5	Consultants	General manager	10 years
6	Universities	Professor	20 years
7	Universities	Assistant professor	6 years

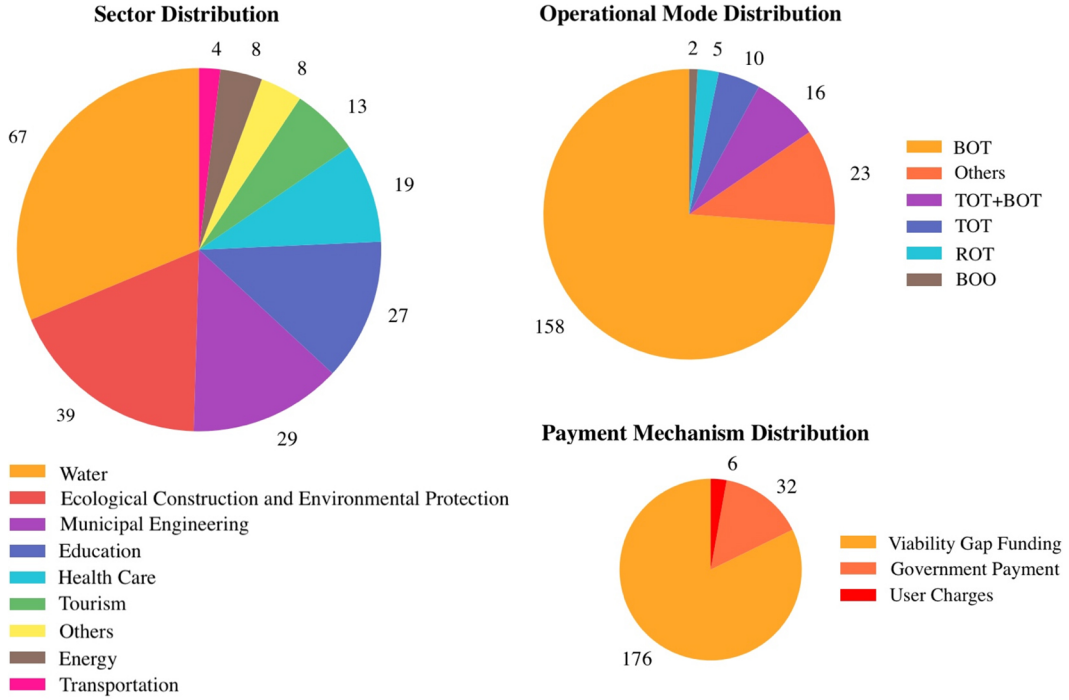


Figure 3. A brief overview of local case database boundaries and parameters

Table 3. Profiles of participants in FGM

Stakeholder group	Number of participants			
	FGM1	FGM2	FGM3	Total
Public Authorities	2	1	2	5
Private Sectors	1	2	2	5
Lenders	1	1	1	3
Suppliers	2	2	1	5
General public	2	4	3	9
Total	8	10	9	27

A focus group meeting (FGM) (Table 3) was further organized to validate the proposed framework in terms of boundaries and the corresponding parameters. The participants raised different concerns about the boundaries according to their experience and roles in the construction industry and proposed suggestions and perceptions on specific parameters regarding each boundary.

The interview transcripts and the developed local case database were analyzed using thematic analysis (TA) to propose a conceptual framework of green PPP, following Braun and Clarke's six-phase framework (Braun & Clarke, 2021) to ensure systematic and rigorous coding and theme development:

I. Familiarization with data: Interview transcripts and local case database were reviewed multiple times to gain an in-depth understanding of the content.
II. Coding: Line-by-line open coding was conducted to identify key features in the data. On the one hand, focus on interviewees' perspectives on the dimensions of green PPP boundaries. The interviewees were grouped according to their managerial and professional roles in their respective stakeholder organizations, and their understanding of green PPP boundary dimensions was identified and coded. The interviewees' perceptions of such dimensions were synthesized and abstracted accordingly. On the other hand, focus on the identification of parameters in each dimension. For instance, codes such as "environmental effect", "green mechanism", "monitoring and reporting" emerged during this phase.
III. Generating initial themes: The initial codes were clustered into broader themes representing dimensions of green PPP boundaries. For example, the code "environmental effect" was subsumed under the theme "external effect", and further classified into "green practice" dimension.
IV. Developing and reviewing themes: Themes were reviewed against the data and refined to ensure consistency. Discrepancies were resolved through team discussions.
V. Refining, defining and naming themes: Themes were defined in terms of their relevance to green PPP boundaries.
VI. Writing up: Direct quotes were used to illustrate how interview data supported the final themes. For instance, one interviewee, a senior officer from public authorities, stated, "The green PPP system boundaries should incorporate external effect assessments as a core component, the social, economic and environmental benefits of the project should be paid attention to." This quote exemplifies the initial identification of themes related to green practice within the green PPP boundaries. Data were then abstracted into categories, such as "environmental effect", "social effect", and "economic effect".

4.3. Supplemental component (qual): international case conceptualization

The proposed framework was developed and validated by local cases, requiring further exploration of real-life project cases worldwide. According to the principles set by Yin (2013), a multiple exploratory case study design was used to identify the different degrees to which the parameters and dimensions associated with green PPP were emphasized within varying case contexts. The units of analysis are the parameters and dimensions of the proposed framework. The case studies took the principle that the "replication of logic" (Yin, 2013) matters rather than any quantitative duplication.

The cases were selected using the purposive sampling principle (Bryman, 2008) to cover as many boundary dimensions as possible for comparison and to increase information accessibility. The selection of case projects considered three principles. First, the cases were selected to allow covering different types of projects in different regions under various political conditions so that the boundaries and parameters under the investigation were exposed to a wide range of contingencies and uncertainties. Second, the selected cases should be constructed contemporarily, which would minimize the fluctuations caused by economic and political situations. Finally, the information on the selected cases should be available and can be obtained with high quality and accuracy.

The desk studies were applied to collect the information from publicly accessible sources (e.g., project websites, brochures), and the results previously published (e.g. articles in academic and professional journals, as cited herein where applicable). The background, progress, and other information on the case project mainly come from the relevant reports of the local government websites and

media pages on the project and related public reports in an effort to reflect the actual progress and effectiveness of the cases. The collected data were first analyzed by the within-case analysis to validate the proposed framework within the global context. The cross-case analysis subsequently synthesized the findings derived from the within-case analysis and then used analytic generalization (Yin, 2013) to compare the parameters identified in each case. All the results were analyzed together to contextualize the proposed framework in a global context.

Aligned with Figure 2, the results and findings derived from the exploration processes of the proposed framework through the sequential qualitative mixed methods (i.e., QUAL → qual) are presented in the following sections.

5. Results and analysis

5.1. Results of the green PPP system boundaries framework development

Based on the identified eight key dimensions, QUAL component aims to verify the system boundaries by interview, explore the parameters associated with each boundary via multiple case study, and further validate the green PPP system boundaries framework through FGM.

The interviews revealed that eight system boundaries addressed the key questions of where, when, who, and how concerning green PPP. The interviewee from public authorities suggested how the project is operated, how the project is paid and how the project is procured well address the how question regarding green project. In terms of when and where questions, the interviewees argued that it is important to consider the timeline of project and varied sectors of green PPP. According to the interview, what kind of green practice is applied and what policy tool is adopted in a project addressed the what question. Meanwhile, the analysis of the interview transcripts found that the green practices boundary can be grouped into two major themes in terms of the project itself and externalities.

More specifically, the green practice of project itself denotes what green practices have been adopted for the project. The analysis of the structured case database, embedded characteristics can be classified as green design, green specification, green technology/technique, green material/equipment, and green mechanism associated with the project implementation. Environmental, social and economic effects in the green practice boundary indicate the positive benefits brought by the project, such as reducing carbon emissions to achieve environmental benefits, improving the quality of community life to address social effects, providing stable income flow and long-term return on investment for economic considerations. Based on the thematic analysis of the interview text and local case database, the parameters associated with each boundary were preliminarily identified (Table 4).

FGM was used to further determine the rationality of these boundaries and the feasibility of the corresponding parameters. Experts generally agreed that the established eight boundaries serve as reasonable system boundaries for green PPP. Thematic coding of the sector identified recurring themes in government priority areas (e.g., transportation, energy). This aligns with sustainability goals as highlighted by several stakeholders: "Government prioritizes sectors contributing to green development and resilience" (FGM 3: Public authorities' participant). Stake-

Table 4. The preliminary parameters associated with system boundary of green PPP

Boundaries	Parameters	
Sector	Municipal Engineering, Ecological Construction and Environmental Protection, Water, Tourism, Energy, Education, Transportation, Health Care, Others	
Stakeholder	Public Authorities, Private Sectors, Lenders, Suppliers, General public	
Procurement model	Open tendering, Competitive negotiation	
Lifecycle	Identification, Preparation, Procurement, Execution, Transfer	
Policy tool	Commanding type	i.e., Code standard, Monitoring and reporting, Institutional improvement
	Incentive type	i.e., Preferential policies, Asset securitization
	Capacity-building type	i.e., Participation of PPP fund, Model contract, Pilot demonstration, Science and technology information support
	System transformation type	i.e., Simplify the approval process, Organizational innovation
	Advising type	i.e., Publicity and promotion, Government encouragement /guidance, Learning and education
Payment mechanism	User charges, Government payment, Viability gap funding	
Operational mode	BOT, TOT, ROT, BOO, TOT+BOT, Others	
Green practice	Project itself	Green design, Green specification Green technology/technique Green material/equipment, Green mechanism
	External effect	Environmental effect, Social effect, Economic effect

holder analysis revealed divergent interests across public and private sectors. Public authorities emphasize compliance with regulatory standards, while private sectors focus on profitability: "For us, it's about cost-effectiveness and timely delivery" (FGM 2: Private sectors' participant). Open tendering emerged as the most widely used model, with stakeholders noting a preference for transparency and fairness: "Open tendering reduces the risk of corruption" (FGM 1: Public authorities' participant). However, competitive negotiation was mentioned as more flexible for complex projects. Policy tools were categorized into themes based on their impact on project implementation. From the perspective of public authorities, commanding tools were the most frequently highlighted. As one respondent noted, "monitoring and reporting tools ensure transparency, which is critical for maintaining accountability" (FGM 1: Public authorities' participant). From the private sector's standpoint, incentive-based tools, such as preferential policies and subsidies, were emphasized as key drivers for participation. A private sector respondent explained, "Incentives reduce risks and enhance the attractiveness of green projects, encouraging investment and innovation" (FGM 1: Private sectors' participant). Thematic coding of payment mechanism revealed a strong preference for government payment mechanisms, with several stakeholders arguing: "Government payments ensure financial stability, especially for large infrastructure projects" (FGM 2: Participants from private sectors and suppliers). However, "Viability gap funding was highlighted as an effective tool for reducing the financing burden" (FGM 2: Participants from public authorities and lenders). Coding of green practices revealed a clear focus on technological innovation: "Green technology/materials help reduce long-term costs and improve sustainability" (FGM 3: Participants from public authorities and suppliers). External effects were widely discussed, especially regarding social impacts, as reflected by this quote: "We need to ensure that green projects provide social benefits to local communities" (FGM 3: Participants from public authorities and general public).

Additionally, experts from the government suggest adding an "Others" option to the dimensions of procurement model to compensate for existing knowledge gaps, since different international organizations and countries may express various opinions on classifying procurement models. Based on the opinions and suggestions of the experts at the symposium, further, a modified and improved conceptual framework of green PPP, as shown in Figure 4.

5.2. Results from multiple contextualization cases analysis

The developed model of green PPP system boundaries is contextualized using four real-life cases in BRICS countries, namely, Hinjawadi to Shivajinagar Pune Metro Line 3 in India, Water Supply and Sewage Treatment PPP project in Rio de Janeiro State, Western Highway Project in Russia and Inkosi Abbott Lutuli Central Hospital Project in South Africa. The selection yielded four cases, which are the studies reported by the BRICS PPP and Infrastructure Working Group. The details of the cases in terms of the system boundaries are provided in Table 5, and see Appendix for complete details.

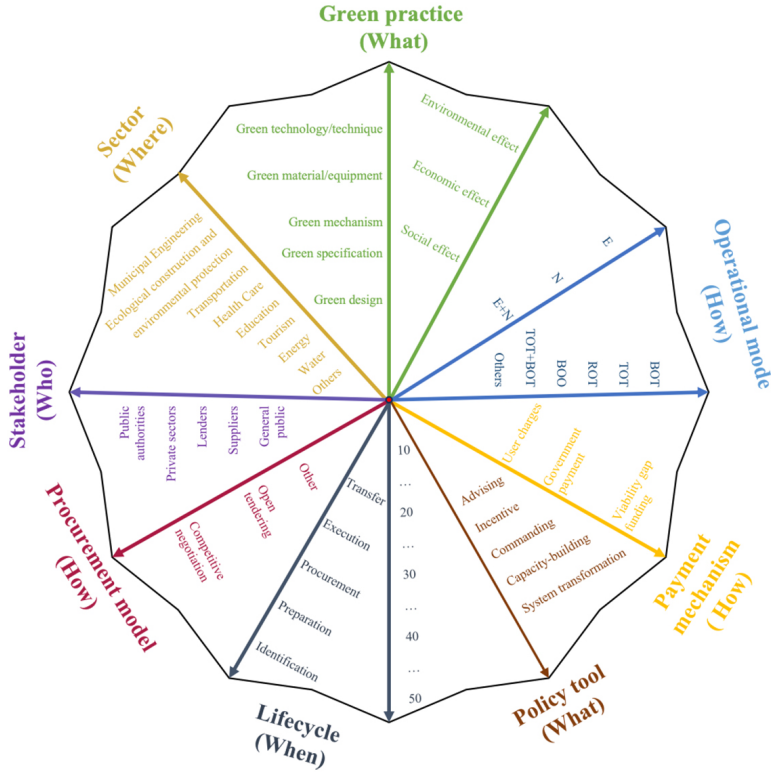


Figure 4. Framework of the green PPP system boundaries

Table 5. Cross-case comparison of system boundaries of green PPP projects

Case	Sector	Stakeholder	Procurement model	Lifecycle		Policy tool (Type)	Payment mechanism	Operational mode		Green practice	
				Lifespan (Years)	Life cycle stage			Status	/	External effect	Project itself
1	Transportation	Public authorities, Private sector, Lenders, General public	Open Tendering	35	Identification, Preparation, Procurement, Execution, Transfer	Incentive	Viability Gap Funding	N	DBFOT	Environmental Social Economic	Green design, Green technology
2	Health Care	Public authorities, Private sector, Lenders, General public	Open Tendering	35	Identification, Preparation, Procurement, Execution	Incentive	User charges	N	DBFOM	Environmental Social Economic	Green technique Green mechanism
3	Transportation	Public authorities, Private sector, General public	Other	30	Identification, Preparation, Procurement, Execution	Incentive	Viability Gap Funding	N	DBFO	Environmental Social Economic	Green design Green technology
4	Health Care	Public authorities, Private sector, Lenders, General public	Other	15	Identification, Preparation, Procurement, Execution, Transfer	Incentive	Government payment	E	FOT	Environmental Social Economic	Green technology Green equipment Green mechanism

- Case 1: Hinjawadi to Shivajinagar Pune Metro Line 3 in India

  The Pune Metropolitan Region Development Authority (PMRDA) collaborated with TRIL Urban Transport Private Limited and Siemens Project Ventures GmbH (TRIL UTPL+SPVG), subsidiaries of the Tata Group, through PPP model to implement this project. The special purpose vehicle (SPV) company Pune IT City Metro Rail Limited was established in 2019. Pune Metro Line-3's geotechnical investigation work started in June 2019 and piling work for construction in November 2020.
- Case 2: Water Supply and Sewage Treatment PPP project in Rio de Janeiro State

  This project is developed with the support of the Ministry of Economy/Investment Partnership Program Secretariat, the Brazilian Development Bank, and the Ministry of Regional Development, aiming to provide water supply, sewage collection, treatment, and commercial management services to 14.2 million users across 49 municipalities in the state of Rio de Janeiro, and promote water supply and sanitation services in the state of Rio de Janeiro.
- Case 3: Western Highway Project in Russia

  This project has a total investment of $3.009 billion USD and, due to its high costs, is implemented under a PPP framework. At its inception, it became the world's largest toll road construction project. The project holds significant importance for the city of St. Petersburg as it constitutes a vital component of the city's transportation infrastructure. It effectively addresses urban transportation infrastructure challenges, enabling smooth traffic flow throughout the day between the northern, central, and southern regions of the city, thus establishing St. Petersburg as a key transportation hub in Russia.
- Case 4: Inkosi Abbott Lutuli Central Hospital Project in South Africa

  As South Africa's first hospital project successfully implemented through the PPP model, this project serves as a representative example of PPP initiatives in South Africa and stands as an outstanding medical center.

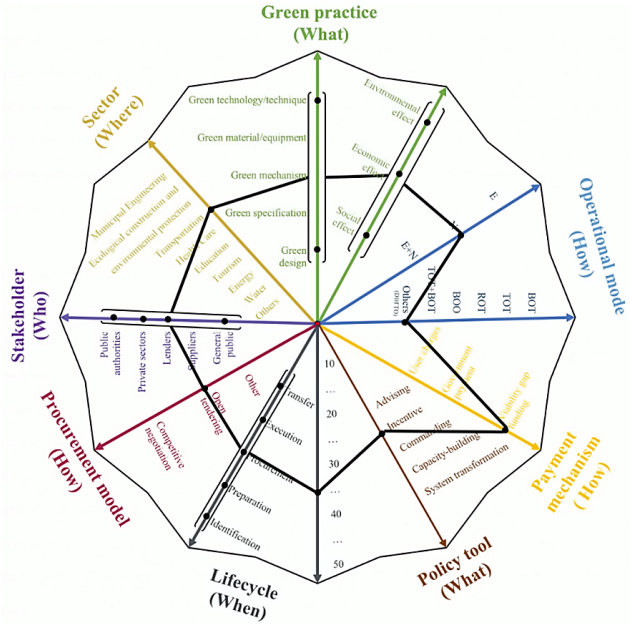
5.3. Cross-case analysis

The selected green PPP projects have a great diversity of boundary for comparison, which are illustrated in a set of four radar maps (Figure 5). System boundaries together address the key questions of what, how, when, who and where, concerning green PPP and several key observations emerge from the comparative analysis:

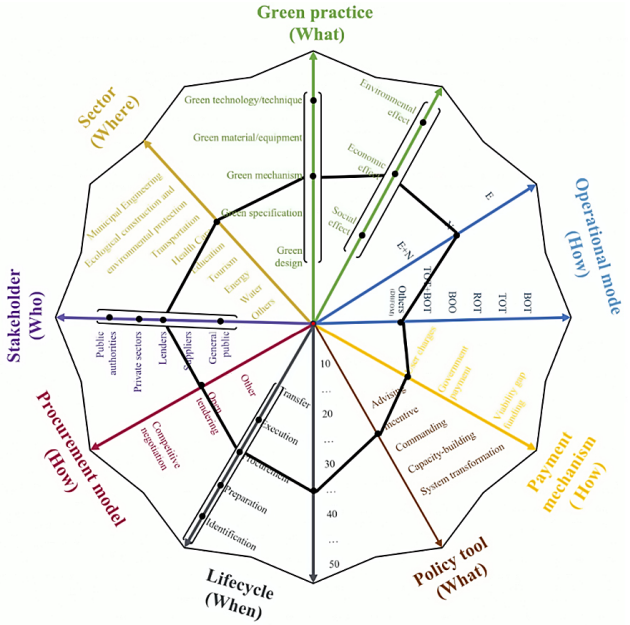
- "What" boundaries: These boundaries answer questions regarding the green practices applied in the projects and the policy tools driving them. In the context of green PPP, the focus is on integrating environmentally friendly practices into infrastructure projects and policies. One of the key questions that green PPP seeks to answer is what green practices have been applied to the project. This involves identifying specific measures that have been implemented to reduce the environmental impact of the project, such as using green design, implementing energy-efficient technologies, or incorporating green mechanism. By incorporating these practices, green PPP brings environmental, social and economic effects, such as helping to reduce carbon emissions, conserve natural resources, and promote environmental

sustainability. Another important question that green PPP address is what kind of policy tool the project is driven by. This refers to the regulatory framework or policy instrument that guides the implementation of green practices within the project. For example, Case 2 is one of the pioneering initiatives developed in accordance with the new legal framework for the healthcare sector in Brazil (Law No. 14,026/2020). The framework stipulates the fundamental objectives that concessionaires must achieve to ensure that more than 14 million people (about 80% of the population of Rio de Janeiro) benefit from the expansion of water supply and sanitation services. By aligning the project with the appropriate policy tool, green PPP can ensure that environmental, social and economic objectives are effectively integrated into the project's design and implementation. Overall, the cases of green PPP provide valuable insights into how public and private sector collaboration can drive sustainable development.

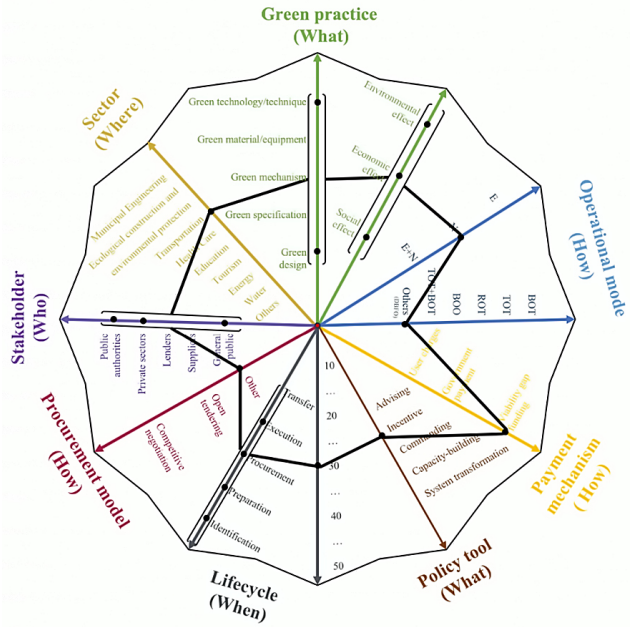
- "How" boundaries: These boundaries answer questions such as how to purchase, operate and fund. In terms of procurement models, the majority of green PPP in China are procured through open tendering, emphasizing transparency and open competition to give all stakeholders the opportunity to participate.



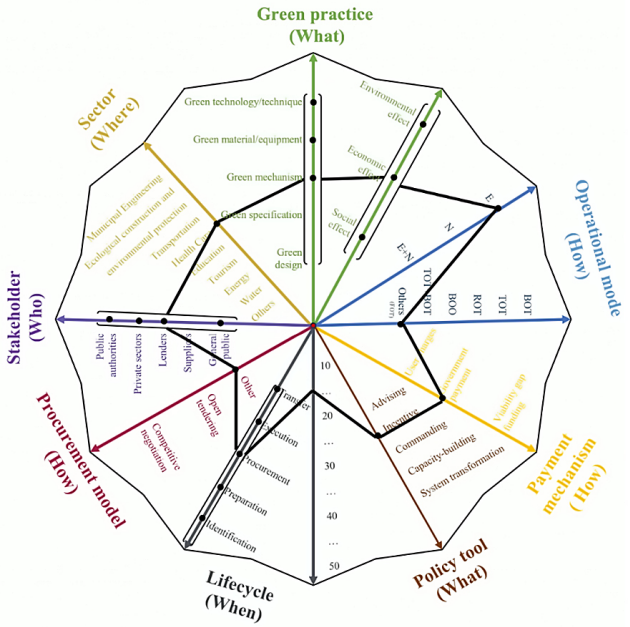
Case 1: Hinjawadi to Shivajinagar Pune Metro Line 3 in India



Case 2: Water Supply and Sewage Treatment PPP project in Rio de Janeiro State



Case 3: Western Highway Project in Russia



Case 4: Inkosi Abbott Lutuli Central Hospital Project in South Africa

Figure 5. Comparative boundary profiles of the selected cases (Note: see Figure 4 for a clearer version of the boundary options)

Among the four selected validation cases, Case 1 and Case 2 were procured through open tendering, while the other two cases were procured through franchising and PPP procurement methods, respectively. This may be due to the inconsistent classification of procurement methods under different national policy backgrounds, and thus they are categorized into other procurement methods in this paper. In terms of operation mode, BOT is the mainstream mode in China at present, but the four selected validation cases use DBFOT, DBFOM, DBFO and FOT respectively, showing that the choice of operational mode depends on the objectives of the PPP, the nature of the project, and the preferences and capabilities of the public and private sector parties involved. Different models offer varying degrees of risk and reward sharing between the public and private sectors. The selection of the appropriate mode is a critical decision in structuring a successful PPP. As for how to get funding for the project, two of the selected cases used user charges and government payment. In fact, usually, economic infrastructure projects are mostly of a user charges type, social infrastructures are viability gap funding, and environmental infrastructure projects are funded through government payment.

- "When" boundaries: These boundaries indicate the varied lifecycle and concession terms of projects. On the whole, most project life cycles include the five key stages mentioned above: identification, preparation, procurement, implementation and transfer, and the concession period of green PPP is relatively long, generally around 30 years. However, the phases included in the life cycle of green PPP are related to its operation mode and project status. For example, a project operating in DBFO (Case 3) mode may not involve the transfer phase, the transfer of ownership is not a primary feature of the DBFO mode. In DBFO mode, a private sector entity is responsible for the entire life cycle of a project, including its design, build, finance and operate.
- "Who" boundaries: These cases indicate varied driving forces. Despite the specific driving forces according to the characteristics of PPP, such as government and private sectors, multiple stakeholders are clearly engaged in the development of green PPP, such as lenders, contractors and general public.
- "Where" boundaries: These boundaries indicate the sectors in which green PPPs are implemented. From the perspective of the industry category, despite the projects with green attributes, such as forestry, ecological construction and environmental protection projects, some municipal engineering, transportation and tourism projects have deeply implemented the concept of green and low carbon.

The case studies suggest that the boundary framework gives valuable insights and facilitates effective comparison of the principles, types and practices associated with green PPP. Although the boundaries are described separately, they are dynamic and interconnected. For instance, lifecycle and stakeholder boundaries interact to influence project development. Different project stages need different management and supervision, and the concession terms stipulate the responsibilities and obligations of all parties, which is crucial for the sustainable development of the project. The sector and green practice boundaries also interact, as the characteristics and environmental impacts of different sectors shape the green practices implemented in each. For example, transportation-focused green practices may include promoting public transport infrastructure and reducing vehicle emissions, while health care projects may prioritize energy conservation, waste reduction, and sustainability initiatives in medical facilities.

6. Discussion

6.1. Climate change and the emergence of green PPP

Climate change, a pervasive environmental challenge, has catalyzed a global response necessitating innovative solutions such as green PPP. The impacts of climate change, including extreme weather events, ecosystem degradation, and resource scarcity, are well-documented and have profound implications for infrastructure development (Intergovernmental Panel on Climate Change [IPCC], 2023; Pauline & Lema, 2024). These environmental shifts exacerbate resource competition and inequality, underscoring the urgency of sustainable infrastructure projects. Green PPP, which integrates sustainability principles into project design and execution, offer a promising avenue for addressing these challenges. For example, PPPs facilitate collaboration between public and private entities, essential for advancing cleaner energy technologies and sustainable development (Cruz et al., 2022). Additionally, understanding and meeting investor demands is crucial for attracting private capital to green PPP projects, which can help bridge funding gaps in low-carbon initiatives (Liu et al., 2023). By delineating the system boundaries of green PPP, stakeholders can pinpoint critical success factors, encompassing environmental and social considerations, and ensuring that sustainability remains central to financing, technology transfer, and policy-making. The proposed system boundaries framework of this study addresses this complexity by offering a systematic and structured approach to understanding green PPP. The framework helps delineate the interconnected components of green PPP projects, facilitating better management and implementation. By recognizing the interplay of environmental, social, and financial goals within the boundaries, the framework ensures a comprehensive understanding of green PPP, providing both theoretical and practical insights for their advancement.

6.2. System boundaries for comprehensive green PPP evaluation

This study proposes a green PPP system boundaries framework for holistically assessing such partnerships within a systemic framework. The proposed boundaries are both conceptual and pragmatic, providing a foundation for future research, policy development, and practical implementation. The framework encourages a shift from descriptive to exploratory research, allowing for a deeper analysis of green PPP dynamics (Alqahtani et al., 2024) and enhancing our understanding of the mechanisms underpinning green PPP success. Defining system boundaries at the project or organizational level supports the comprehensive learning and rapid adoption of green practices, empowering project teams and organizations to develop informed management strategies tailored to their specific interests and contexts. Future research could benefit from a comparative analysis of global green PPP practices to identify and promote best practices (Vassileva, 2022). Theoretically, the framework contributes to the literature by addressing the complexity of green PPPs and deepening our understanding of the interrelations among their diverse components, thereby advancing the theoretical discourse on sustainable infrastructure projects (Vassileva, 2022). By examining the dynamics between these interconnected elements, the framework offers valuable insights into how sustainability goals can be systematically integrated into the project lifecycle. Moreover, it serves as a comparative platform for analyzing green PPPs across different global contexts, facilitating the identification of universal principles and patterns that can inform both theory and practice. This contribution enhances the transferability of theoretical insights across different sectors and geographies, promoting a more sustainable infrastructure development model (Cruz et al., 2022).

6.3. Information integration and PPP project management

PPP projects are inherently information-intensive, involving numerous stakeholders across various disciplines and project phases. This complexity can lead to "broken agency" within stakeholder networks, highlighting the need for effective information integration to ensure efficient project management (Casady et al., 2020; Cui et al., 2018). The proposed framework can serve as a tool for facilitating this integration, ensuring all stakeholders with the project's sustainability goals (Darko et al., 2023). By enhancing managers' ability to navigate the interdependencies within and between boundaries, the framework is crucial for the successful implementation of green PPP projects. Adopting a system thinking approach allows managers to identify and manage key relationships, ensuring that sustainability goals are pursued in a coordinated and holistic manner. Additionally, it improves stakeholder alignment, fostering collaboration and efficient decision-making throughout the project lifecycle. For government agencies, the framework offers a taxonomy for classifying green PPP projects, providing a clear basis for policy development. This classification helps tailor regulatory measures and policies to the specific characteristics of different green PPP projects, thereby improving policy effectiveness and implementation. By clarifying how green PPP function across various boundaries, the framework helps policymakers design targeted interventions that foster sustainable practices in infrastructure projects.

7. Conclusions

This study explores the system boundaries of green PPP and develops a conceptual framework encompassing eight boundary categories: sector, stakeholder, procurement model, lifecycle, policy tool, payment mechanism, operational mode, and green practice. These dynamic and interrelated boundaries provide a comprehensive lens for understanding the complexities of green PPP. By synthesizing case studies and validating findings through semi-structured interviews, the framework reveals the diversity and complexity of green PPP boundaries, offering both practical and theoretical insights for future PPP research, operational practices, and policy evaluation. Comparative analyses of principles, policies, practices, and priorities within these boundaries could deepen our understanding and advance green PPP practices.

This study has limitations that future research should address. Although regional and industry diversity was considered, the cases focused predominantly on China, potentially limiting the generalizability of findings. Further empirical studies across more countries and sectors are needed to refine and validate the framework. Additionally, while this study includes cases from BRICS countries, a deeper analysis of implementation outcomes and influencing factors was beyond its scope. Future research should examine the effectiveness and impacts of green PPP projects in practice to strengthen empirical support for the framework. Lastly, as an exploratory study, this paper primarily focused on conceptual development. While expert interviews enhanced the model's reliability, the lack of quantitative data limits insights into the interaction between green PPP projects and sustainability outcomes. To guide future studies, the following research questions are proposed: What are the key factors influencing the success of green PPP within the proposed framework? How can green PPP projects be clustered based on the proposed boundaries, and what targeted policy recommendations can be derived for each cluster? How does the proposed framework perform when validated and analyzed in green PPP projects in developed countries? These questions aim to further explore and refine the utility of the proposed framework, both theoretically and practically, and provide a foundation for advancing research on green PPP.

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Disclosure statement

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

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APPENDIX

Identification details of system boundaries of green PPP projects in BRICS countries

Table A1. Overview of Hinjawadi to Shivajinagar Pune Metro Line 3 in India (Case 1)

Boundaries	Description	Parameter
Sector	The objective of this project is to optimise the existing transportation system and facilitate the transition from private car usage to public transportation.	Transportation
Stakeholder	The Tripartite Agreement between the Central Government, the Lead Financial Institution and the Concessionaire is signed in May 2022. Around 2.61 lakh would be serviced (estimated by DMRC for the year 2021) commuters daily.	Public authorities, Private sector, Lenders, General public
Procurement model	Through two-stage (RFQ and RFP) tendering, PMRDA announced the final bidder for the project – the joint venture Tata Realty-Siemens on 3 August 2018.	Open Tendering
Lifecycle	The project operates under a 35-year concession agreement (Identification, Preparation, Procurement, Execution, Transfer), including a 3-year construction period.	35-year
Policy tool	This is the first project to be implemented on the PPP basis under the Central Government's New Metro Rail Policy 2017.	Incentive type
Payment mechanism	The Concessionaire shall contribute about Rs. 1315 cr for the development of the Project. About Rs. 4789 cr shall be funded through debt and the State Bank of India has been identified as Lead Financial Institution for the project. The Central Government shall contribute Rs. 1225 cr during the construction phase as Viability Gap Funding. The State Government shall contribute Rs. 90 cr during the construction phase and about Rs. 1035 cr during operations phase as State's share of Viability Gap Funding. The Government of Maharashtra in its Resolution dated 27th August 2019 has allotted 10.6-hectare land owned by Government Polytechnic, 7.14-hectare land owned by Dairy Development Board and 4.17-hectare land owned by Pune Rural Police and Wireless Department to the Authority for monetisation to meet the State Government's share of Viability Gap Funding for the Project. Other expenses like land acquisition, utility shifting, double decker flyover etc. shall be borne by the Authority and the State Government.	Viability Gap Funding
Operational mode	On 3 October 2018, Tata Realty-Siemens were awarded the contract to execute the project on a design, build, finance, operate and transfer model.	DBFOT
Green practice	The Energy-efficient Building Association of India (IGBC) has developed a green rapid transit system (MRTS) rating tool for all stations and a green factory building rating system for storage stations. These rating tools urge the new mass rapid transit system to apply green concepts in the design and construction process to further reduce the measurable environmental impact. At the peak of construction, about 1000 people participated in the construction work, and the project directly provided a large number of employment opportunities. In addition, more people are indirectly employed in related activities and industries. In medium to long run, this will result in significant reduction in travel time, fuel costs and travel expenses along with lowering of noise and air pollution. Eventually it will help to attract more investments in the region paving way for further growth and prosperity of the region.	Green design, Green technology, Environmental effect, Social effect, Economic effect

Table A2. Overview of Water Supply and Sewage Treatment PPP project in Rio de Janeiro State (Case 2)

Boundaries	Description	Parameter
Sector	This project is one of the pioneering initiatives developed in accordance with the new legal framework for the healthcare sector in Brazil (Law No. 14,026/2020). It falls within the priority area of health facilities (Law No. 9,036/2017).	Health Care
Stakeholder	The implementing agency of this project is the government of the state of Rio de Janeiro. Private sectors include AEGEA Saneamento, Iguá Saneamento, and Águas do Brasil. It is supported by the Brazilian National Development Bank (BNDES). The project will benefit over 14 million people, approximately 80% of the population of the state of Rio de Janeiro, by expanding the coverage of water supply and sanitation services.	Public authorities, Private sector, Lenders, General public
Procurement model	The project underwent two open tenders: in April 2021, the first tender encompassed Blocks 1, 2, and 4, with a total concession fee of 22.7 billion Brazilian reais, covering 29 municipalities. In December 2021, the second tender exceeded 2.2 billion Brazilian reais in concession fees, encompassing an additional 20 towns and parts of the city of Rio de Janeiro.	Open tendering
Lifecycle	The project operates under a 35-year concession agreement (Identification, Preparation, Procurement, Execution).	35-year

End of Table A2

Boundaries	Description	Parameter
Policy tool	This project is one of the pioneering initiatives developed in accordance with the new legal framework for the healthcare sector in Brazil (Law No. 14,026/2020). The framework stipulates the fundamental objectives that concessionaires must achieve: in compliance with legal provisions, concessionaires are required to ensure that by December 31, 2033, 99% of the urban population has access to water supply services, and 90% of urban households in cities under concession have access to sewage collection and treatment services.	Incentive type
Payment mechanism	The project divides the urban and suburban areas of Rio de Janeiro city into four blocks, granting them to private sectors to leverage their expertise, enhance operational efficiency, and improve service quality. Project revenue is derived from end-users.	User charges
Operational mode	The project operates under the Design-Build-Finance-Operate-Manage (DBFOM) mode.	DBFOM
Green practice	The project is anticipated to have significant positive economic impacts on the state in the medium to long term. Furthermore, it is estimated that investments in infrastructure projects during the initial years of the concession will create approximately 45,000 job opportunities. During the initial five years of the concession period, the private sectors will invest approximately 3 billion Brazilian reais to mitigate pollution in Guanabara Bay and its tributaries, thereby enhancing the water quality of rivers and lakes. Additionally, an investment of 2.9 billion Brazilian reais will be allocated to reduce pollution in the primary water source for the metropolitan area of Rio de Janeiro state, the Guandu River. Furthermore, 250 million Brazilian reais will be invested in the clean-up of Jacarepaguá and Barra lakes.	Green technique, Green mechanism, Environmental effect, Social effect, Economic effect

Table A3. Overview of Western Highway Project in Russia (Case 3)

Boundaries	Description	Parameter
Sector	The project constitutes a vital component of the transportation infrastructure in St. Petersburg, effectively addressing urban transportation infrastructure issues.	Transportation
Stakeholder	The municipal government of St. Petersburg and OJSC Western High-Speed Diameter serve as the implementing agencies for the project, with Northern Capital Highway LLC acting as the procured social capital entity. The ownership distribution between the public sector and social capital stands at 49.3% and 50.7%, respectively.	Public authorities, Private sector, General public
Procurement model	Concession agreement.	Other
Lifecycle	This project cooperation period is 30 years.	30-year
Policy tool	Russia actively uses PPP model to achieve economic, social and environmental development goals, and this project is one of the strategic economic PPP projects in Russia.	Incentive type
Payment mechanism	This project includes both government fees and user fees.	User charges, Government payment
Operational mode	This project operates in Design-Build-Finance-Operate (DBFO) mode.	DBFO
Green practice	The project involves complex artificial structures, primarily including a double-deck bridge using the balanced cantilever method for channel navigation, cable-stayed bridges on the Petrovsky Channel, and the Kola Bay Channel (the world's only cable-stayed bridge with inward-leaning towers). Industry-leading companies such as KPMG, Capital Legal Services, Herbert Smith Freehills, and AECOM serve as legal and financial advisors for the project. The project has generated significant employment opportunities and acted as a catalyst for economic development in St. Petersburg, driving construction in the northwestern regions of the city and attracting domestic and international investors. By stimulating commercial activities and enhancing the value of properties adjacent to the highway, it has spurred growth in employment and fiscal revenue. The project has catalysed a new commercial development center in the northwestern part of St. Petersburg. For instance, one of Russia's largest companies, Gazprom, relocated its headquarters from Moscow to the Lakhta Center skyscraper near the project site. Additionally, the project has reduced traffic congestion in downtown St. Petersburg, leading to a decrease in air pollution.	Green design, Green technology, Environmental effect, Social effect, Economic effect

Table A4. Overview of Inkosi Abbott Lutuli Central Hospital Project in South Africa (Case 4)

Boundaries	Description	Parameter
Sector	This project is the first hospital project successfully implemented in PPP mode in South Africa.	Health Care
Stakeholder	Consulens: Provides medical equipment. AME Africa: Provides Information Management & Technology (IM&T) services. Tsebo Facilities Management: Provides hardware and software facility management. Private sector: Impilo consortium.	Public authorities, Private sector, Lenders, General public
Procurement model	PPP	Other
Lifecycle	This project cooperation period is 15 years, excluding the construction and development stages.	15-year
Policy tool	This project is implemented in accordance with Regulation 16 of the National Treasury, making it the first hospital in South Africa to provide non-clinical services using the PPP model.	Incentive type
Payment mechanism	With the support of the provincial finance department and the Ministry of Finance, the project has provided highly specialised services to 11.5 million people in KwaZulu, natal province and parts of eastern cape, and implemented the principle of paperless and fully computerised.	Government payment
Operational mode	The operation mode of the project is financing-operation-transfer (FOT) (the building has been completed).	FOT
Green practice	The hospital is regarded as the government facility with the highest employment rate in non-clinical sectors, boasting comprehensive information management technology, medical equipment, facility management, and a highly skilled, experienced team of experts. This partnership contributes to maintaining investment levels in the province, creating job opportunities, and improving the business environment in information management technology, medical equipment, and other areas. With its considerable procurement scale, the project has made a significant contribution to the economic development of the province. Leveraging Information Management & Technology (IM&T) services, the hospital has implemented an electronic medical record system through a medical order transmission system. Online reports, including electronic prescriptions and medication records, help save hospitalisation time and expedite patient turnover. The effectiveness of the hospital's electronic systems is further demonstrated by operating room and outpatient scheduling systems, as well as digital imaging.	Green technology, Green equipment, Green mechanism, Environmental effect, Social effect, Economic effect