



PUBLIC–PRIVATE PARTNERSHIPS FOR GREEN INFRASTRUCTURE: THE ROLE OF RENEWABLE ENERGY

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Abstract

Financing green infrastructure requires arrangements capable of addressing high initial capital needs and long-term performance requirements. This paper examines the application of Public–Private Partnerships (PPPs) to renewable energy, energy-efficient buildings, and related forms of green infrastructure. The study combines a structured qualitative review of scientific and institutional sources with selected international and Serbian project cases. The analysis identifies risk allocation, life-cycle management, regulatory predictability, institutional capacity, and contractual design as important factors affecting PPP performance. International cases include energy-efficient public lighting, solar-energy development, and waste-to-energy infrastructure, while Serbian examples cover public-lighting and biomass-based heating projects in Niš, solar generation in Vranje, and the Vinča waste-management PPP in Belgrade. These applications are interpreted through an integrated conceptual framework linking infrastructure investment needs and project risks with PPP mechanisms and economic, environmental, and social outcomes. For Serbia, the findings also indicate potential for further application in public-building energy renovation, renewable-energy systems, low-carbon district heating, and urban green and blue infrastructure.

Key words: public–private partnerships; green infrastructure; renewable energy; sustainable development; infrastructure financing.

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1. INTRODUCTION

The transition toward low-carbon and resource-efficient infrastructure is increasing demand for renewable energy systems, energy-efficient buildings, and other forms of sustainable public infrastructure. These projects often combine high initial capital requirements with long implementation periods and benefits realized over a longer horizon, creating financing challenges where public budgets are constrained [1–5].

Public–Private Partnerships (PPPs) can combine public-sector objectives with private financing, technical expertise, innovation, and long-term asset management. In green infrastructure, their relevance also lies in risk allocation, life-cycle considerations, and performance-based contractual mechanisms, which are particularly important where project viability depends on long-term efficiency, regulatory stability, and technological performance [6–10].

Existing research often treats PPP financing and governance, renewable-energy investment, and green-building performance separately. An integrated perspective is therefore useful for linking PPP financing characteristics with the specific requirements of sustainable infrastructure projects [7–12].

Accordingly, this paper examines the role of PPPs in financing green infrastructure, with particular emphasis on renewable energy systems and green buildings. It organizes these relationships within an integrated framework linking financing constraints, risk allocation, institutional capacity, and sustainability outcomes, and interprets selected international applications together with cases from Niš, Vranje, and Belgrade to identify further opportunities for green-oriented PPPs in Serbia.

2. LITERATURE REVIEW

The review combines peer-reviewed publications with reports, guidelines, and policy documents from UNEP, the European Union, IEA, IRENA, OECD, the World Bank Group, and EPEC. Sources span 2012–2026 and were selected for relevance to three interconnected areas: green infrastructure and green buildings, renewable-energy development and financing challenges, and PPP models for sustainable infrastructure. Earlier sources were retained where they provide relevant theoretical foundations or documented project experience.

2.1. Green Infrastructure and Green Building

Green infrastructure integrates environmental protection, resource efficiency, climate resilience, and long-term economic considerations into infrastructure planning and urban development. Compared with conventional infrastructure approaches, it places greater emphasis on reducing environmental impacts throughout the project life cycle and on improving the resilience and efficiency of infrastructure assets. Governments and international organizations increasingly incorporate these principles into policies aimed at climate neutrality, urban resilience, and the transition toward a low-carbon economy [1–4].



Within this broader concept, green buildings represent an important component of sustainable infrastructure. Green buildings are designed, constructed, and operated to minimize energy consumption, reduce greenhouse gas emissions, optimize water use, improve indoor environmental quality, and promote the efficient utilization of construction materials. Their performance is evaluated not only through environmental criteria but also through economic and social indicators, including operational cost savings, occupant health, and long-term asset value [1, 2].

International certification systems such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and the German Sustainable Building Council (DGNB) provide standardized frameworks for assessing building sustainability. These systems incorporate criteria related to energy efficiency, resource use, environmental performance, and life-cycle considerations, thereby supporting more consistent evaluation of green building projects [2].

Green building projects may require higher initial investment than conventional buildings because energy-efficient systems, sustainable materials, and advanced building technologies often increase upfront costs. However, part of this additional expenditure may be offset over the project life cycle through lower energy consumption, reduced operating costs, and improved asset performance. This investment profile creates a particular financing challenge, especially for public authorities facing budget constraints, and increases the relevance of financing models capable of combining public and private resources and considering long-term project performance [5, 9].

2.2. Renewable Energy Development and Financing Challenges

Renewable-energy investment has expanded as energy systems incorporate solar, wind, hydropower, biomass, and geothermal technologies. These technologies support emissions reduction, energy-supply diversification, and long-term energy security, while international climate and energy policies further encourage investment [3, 4].

Renewable-energy projects nevertheless face high upfront costs, long recovery periods, technological uncertainty, regulatory and market risks, permitting and grid-connection requirements, and dependence on public-support mechanisms [3, 4, 8]. Predictable legal frameworks, transparent procurement, appropriate contracts, and balanced risk allocation can improve bankability and private-sector participation [8, 11].

These characteristics increase the relevance of financing structures that combine public objectives with private capital and expertise. PPPs are one possible approach where renewable-energy projects include a clear public-service or infrastructure component, but their suitability depends on project characteristics, revenue mechanisms, regulatory stability, and public-sector capacity [6, 8, 11].

2.3. Public–Private Partnerships in Green Infrastructure

PPPs are long-term contractual arrangements in which public and private partners share responsibilities for financing, design, construction, operation, or maintenance of

infrastructure and public services. Their sectoral structure varies across countries and levels of development [13], while the central objective is to combine public supervision with private financing, technical expertise, and operational capacity [6, 10].

Risk allocation is central to PPP design. Construction, operational, technological, financial, regulatory, and demand risks should be assigned to the party best able to manage them; poor allocation can increase costs and reduce value for money, whereas balanced responsibilities can improve long-term performance [6, 8, 10, 14, 15].

Although PPPs have traditionally been used in transport, water, healthcare, education, and utilities, their application has expanded to renewable energy, energy-efficient public buildings, district heating, waste management, and public lighting [7–9]. In green infrastructure, long-term contracts can support life-cycle cost management, performance-based maintenance, energy-efficient technologies, and specialized operational responsibilities [6, 10, 14].

PPP effectiveness depends on project preparation, procurement quality, regulatory predictability, public-sector capacity, and contract management. Weak institutions or poorly specified obligations can reduce expected economic and environmental benefits, so PPPs should be compared with alternative procurement and financing models before implementation [6, 10, 15]. Figure 1 summarizes the conceptual framework applied in this paper.

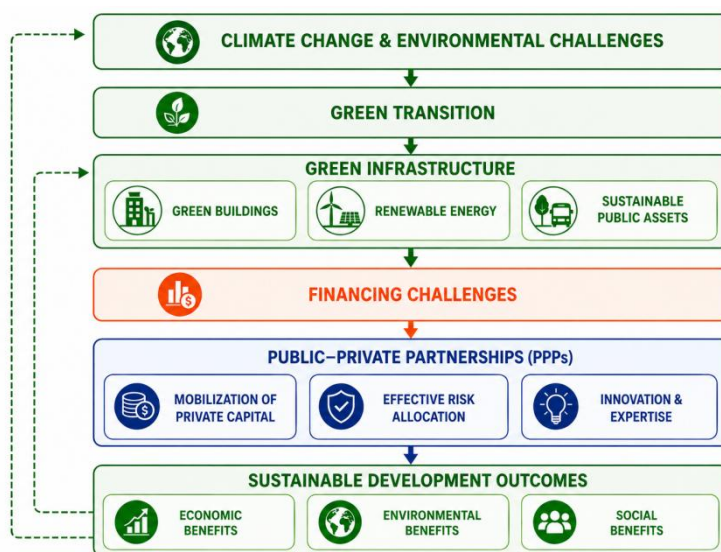


Figure 1. Conceptual framework illustrating the role of Public-Private Partnerships in financing green infrastructure development. Source: Authors' illustration based on the reviewed literature.

Figure 1 links green-infrastructure demand, financing constraints and project-specific risks with PPP mechanisms and sustainability outcomes. PPPs are positioned as an intermediary contractual and financing mechanism through which private capital, technical expertise, risk allocation, and long-term asset management may be combined with public-sector objectives. Their contribution depends on whether the selected structure addresses the project's financing, technological, operational, and institutional constraints.



The resulting outcomes can be assessed across economic, environmental, and social dimensions, including life-cycle efficiency, environmental performance, service quality, and long-term infrastructure sustainability. This framework provides the analytical basis for the financing mechanisms and project cases discussed below.

3. PUBLIC–PRIVATE PARTNERSHIPS AS FINANCING MECHANISMS FOR GREEN INFRASTRUCTURE

3.1. Benefits of PPPs in Green Infrastructure Development

The financing of green infrastructure often requires contractual arrangements capable of addressing high initial investment costs together with long-term operational and performance requirements. PPPs can support this process by combining public-sector objectives with private financing and by distributing financing, construction, operational, and technological responsibilities across the project life cycle [6, 12].

Risk allocation represents one of the main channels through which PPP structures can influence project performance. Where individual risks are assigned to the party with the greater capacity to manage them, PPP arrangements may improve cost control and reduce the probability that construction or operational problems are transferred entirely to the public sector. However, risk transfer does not automatically generate value for money; its effectiveness depends on contractual design, project preparation, and the ability of both partners to manage their allocated responsibilities [6, 10, 14, 15].

The long-term structure of PPP contracts may also create incentives to consider operating and maintenance costs during project design and construction. This is particularly relevant for energy-efficient buildings, public lighting, heating systems, and renewable-energy infrastructure, where project performance over time can determine both financial and environmental outcomes. Private partners may additionally contribute specialized technical expertise, energy-management systems, digital monitoring, and other technologies that improve asset performance during operation [3, 7, 11].

The potential benefits of PPPs therefore depend less on the formal designation of a project as a PPP and more on whether the contractual structure improves financing conditions, risk management, life-cycle performance, and service delivery compared with alternative procurement approaches. At a broader level, PPP investment may also generate economic benefits through infrastructure provision and the mobilization of private capital, particularly in developing economies [16]. The following examples illustrate how these mechanisms have been applied in practice.

3.2. Selected PPP Applications in Green Infrastructure: International and Serbian Experience

PPP arrangements have been applied to energy-efficient public lighting, renewable-energy generation, waste management, and urban energy systems. Table 1 combines



selected international and Serbian cases to show how private financing, risk allocation, and operational responsibility can be adapted to different technologies and project scales.

In the United Kingdom, public-lighting PPPs have supported replacement of inefficient equipment with energy-efficient lighting, reducing electricity use and operating costs [17]. In India, PPP-related approaches have supported large-scale solar development by combining public infrastructure and coordination with private investment and technical capacity [18]. In China, waste-to-energy PPPs combine municipal waste treatment, private financing, long-term contracting, and energy recovery [19].

Table 1. Selected PPP Applications in Green Infrastructure

Country / City	Selected PPP application	Green dimension / relevance
United Kingdom (Croydon)	Street-lighting modernization [17]	Energy efficiency; lower electricity consumption and operating costs.
India	Solar parks program [18]	Large-scale renewable-energy deployment through solar infrastructure.
China	Waste-to-energy PPP projects [19]	Waste treatment combined with energy recovery.
Serbia, Niš	Replacement, rationalization and maintenance of public lighting [20]	Municipal energy efficiency and reduced electricity demand.
Serbia, Niš	Substitution of fossil-fuel heat production with wood biomass [21]	Renewable heat, lower fossil-fuel use and reduced emissions.
Serbia, Vranje	Two solar power plants in the Vranje Free Zone [22]	Local solar-energy generation and renewable infrastructure.
Serbia Belgrade (Vinča)	Waste-management and waste-to-energy PPP [23]	Landfill remediation, modern waste treatment and energy recovery.

Serbian cases show green-oriented PPP applications at different local-infrastructure scales. In Niš, public-lighting modernization targets lower electricity demand and maintenance requirements [20], while a district-heating proposal substitutes fossil-fuel production with wood biomass, with the private partner financing equipment and assuming relevant technical and financial risks [21]. This is consistent with broader recommendations for private-sector participation in district-heating modernization [24].

A further Niš project replaces fuel-oil boilers in schools and preschool facilities with biomass, pellet, or natural-gas systems [25]. In Vranje, a concession proposal covers financing, design, construction, connection, management, and maintenance of two solar power plants [22]. At a larger scale, the Belgrade Vinča PPP combines landfill remediation, waste treatment, and energy recovery, mobilizing substantial private and institutional financing [23].

Together, the cases illustrate PPP applications in energy efficiency, solar generation, renewable heating, and waste-to-energy infrastructure, while also showing the role of local authorities in identifying projects suitable for long-term public-private cooperation.

Further Serbian applications could include ESCO-type renovation of public buildings, rooftop photovoltaics and storage, low-carbon district heating, and urban green and blue infrastructure. Recent public-building initiatives already combine envelope



measures, photovoltaics, heat pumps, efficient lighting, and automated energy management [26], while district-heating modernization can incorporate biomass, heat pumps, solar thermal systems, and waste-heat recovery [24]. These directions align with Serbia's broader decarbonization investment needs [27].

3.3. Challenges and Future Perspectives of PPPs in Green Infrastructure

The implementation of PPP projects in green infrastructure is affected by financial, regulatory, institutional, and political risks that can influence project costs and private-sector participation. High transaction costs, lengthy procurement procedures, regulatory uncertainty, and changes in public policy are particularly relevant in developing and emerging markets, where they may weaken project bankability and increase implementation risks [6, 8, 11].

Financial sustainability represents an additional challenge because green infrastructure generally combines high initial investment requirements with long operating and repayment periods. Private participation therefore depends on credible revenue mechanisms, predictable regulatory conditions, and, where justified, appropriate public support. Inadequate project preparation, unrealistic demand assumptions, or poorly structured financial obligations can undermine long-term project performance [6, 14, 15].

Institutional capacity is equally important. Public authorities must be able to prepare feasibility studies, structure procurement procedures, allocate risks, and monitor long-term contracts. Limited technical and administrative capacity may result in delays, inappropriate risk allocation, contract renegotiation, or additional fiscal exposure [10, 12].

Future PPP structures may increasingly be combined with complementary financing instruments, including green bonds, blended finance, climate funds, and other sustainability-oriented sources of capital [3, 4, 11]. Digital technologies may also support project preparation and contract management. Building Information Modelling (BIM), digital twins, smart monitoring systems, and data-based performance assessment can improve the monitoring of energy use, operating conditions, and life-cycle asset performance.

The further application of PPPs to green infrastructure will therefore depend on the quality of project preparation, institutional capacity, contractual design, and the ability to measure long-term performance. For Serbia, the cases discussed in the previous section indicate potential in municipal energy efficiency, renewable heating, solar energy, public buildings, and environmental infrastructure, while broader application will require continued strengthening of project-development capacity and financing conditions [24, 27].

4. CONCLUSION

Green infrastructure projects, particularly renewable-energy systems and energy-efficient buildings, combine substantial initial investment requirements with long operating periods and performance objectives that extend beyond conventional

infrastructure delivery. The reviewed literature indicates that PPPs can address some of these characteristics by combining private financing and technical capacity with long-term risk allocation, operation, and asset-management responsibilities. Their suitability, however, depends on project characteristics and on whether the selected contractual structure provides advantages over alternative procurement and financing approaches.

The analysis implies that regulatory stability, transparent procurement, appropriate risk allocation, institutional capacity, and consistent long-term project management remain central to PPP performance. These factors are particularly relevant in green infrastructure, where financial outcomes are often linked to energy savings, technological performance, environmental requirements, and life-cycle costs. PPP arrangements should therefore be assessed not only according to their ability to mobilize private capital, but also according to their capacity to improve long-term project performance and allocate responsibilities effectively.

The international and Serbian cases presented in this paper demonstrate the diversity of possible applications. International experience includes energy-efficient public lighting, solar-energy development, and waste-to-energy infrastructure, while Serbian practice provides examples of public-lighting modernization, biomass-based district heating, improvements to heating systems in public buildings, solar generation in Vranje, and the large-scale Vinča waste-management PPP in Belgrade. These cases indicate that green-oriented PPPs in Serbia are already being applied at different project scales, with local authorities playing an important role in identifying suitable infrastructure needs.

Based on this experience, further application in Serbia could extend toward comprehensive energy renovation of public buildings, rooftop photovoltaic systems and energy storage, low-carbon district-heating solutions, and urban green and blue infrastructure. The viability of such projects will depend on careful project preparation, measurable performance requirements, appropriate financing structures, and sufficient institutional capacity rather than on the PPP model alone.

By linking green-infrastructure investment requirements, renewable-energy financing constraints, project risks, and PPP mechanisms within a common analytical framework, the paper provides a basis for comparing different applications of public-private cooperation in sustainable infrastructure. Future research should assess the actual financial, energy, and environmental performance of completed green PPP projects and compare their outcomes with alternative infrastructure-delivery models.

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