WHOLE-LIFE ASSET MANAGEMENT AND CIRCULAR ECONOMY PRINCIPLES FOR PUBLIC-PRIVATE PARTNERSHIPS (PPPs): TOWARDS SUSTAINABLE INFRASTRUCTURE

By

***Muskan Sehgal, **Sejal Sagar, & ***Pranav Vaishnav**

**Student, Department of Commerce, CHRIST (Deemed to be University), Bangalore, Karnataka, India.*
***Student, Department of Commerce, CHRIST (Deemed to be University), Bangalore, Karnataka, India.*
****Student, Department of Commerce, CHRIST (Deemed to be University), Bangalore, Karnataka, India.*

Abstract

Public-private partnerships (PPPs) are growing to become more popular despite the dynamic demands for sustainable infrastructure. Nonetheless, short-term delivery and linear asset lifecycles continue to be given priority in current models. The study investigates how public infrastructure projects' long-term sustainability, adaptability, and value can be increased by incorporating whole-life asset management and circular economy (CE) principles into PPP frameworks. The project's goal is to produce information that will be helpful in combining PPP incentives with more general social, economic, and environmental goals.

Methodology: *The study synthesises theoretical and practical advancements in PPP whole-life management and circularity integration by drawing on a wide range of case studies, international policy frameworks, and scholarly and industry literature. It uses a qualitative system analysis to identify barriers in the process of implementation as well as organisation, technology, financial, and governance.*

Findings: *Traditional PPP practices often neglect asset longevity, adaptability, and resource recovery, which leads to societal outcomes that are not ideal. Integrating the principles of a circular economy and whole life asset management perspectives improves environmental and social value, decreases waste and lifecycle costs, and improves the performance of the asset. Reimagining contract structures, using different metrics to its advantage, and encouraging digital innovation through the use of blockchain and BIM creates adaptable collaborative partnerships that balance the interests of conflicting stakeholders necessary for success.*

Practical Implications: *Policymakers can support the circular economy along with whole-life PPPs by changing procurement and performance standards, encouraging the usage of digital infrastructure, and increasing the capacity in both public and private sectors. Professionals should prioritise risk management, stakeholder engagement, usage of data-driven information, and flexible contracts with lifecycle incentives.*

Keywords: *sustainable infrastructure, circular economy, whole-life asset management, ppps, lifecycle approach, contract innovation, and digital transformation.*

Introduction

A fundamental component of modern infrastructure development takes place through public-private partnerships (PPPs). Public-private partnerships enable governments to make use of private finance and innovation to address the various needs for public services. PPPs have been used worldwide since the 1990s, funnelling billions of dollars a year into building and maintenance of public infrastructure like hospitals, power plants, roads, railroads, transit systems, and digital networks (Demirag, Khadaroo, Stapleton, & Stevenson, 2011). By taking advantage of the efficiency of the private sector, transferring project risks from the public sector, and ensuring high standards through performance-based contracting, PPPs aim to deliver better value for the money invested (Khanom, 2010).

However, these positive narratives are controlled by two persistent critiques. First, too many PPPs still focus on narrow, short-term project milestones like delivery on time and on budget, neglecting the long-term issues such as maintenance, adaptability to changing needs and environment, and life-cycle costs that accrue over decades (Shen, Tam, Gan, Ye, & Zhao, 2016; Liu et al., 2015). Second, most PPPs continue to follow a linear "design, build, operate, dispose" logic, rarely considering what happens after decommissioning and missing opportunities to retain value through the reuse and recycling of materials principles at the heart of the circular economy (Akomea-Frimpong, Jin, & Osei-Kyei, 2022).

This traditional 'take make dispose' model exhaberates waste processing, resource depletion, and missed opportunities for value recovery, running counter to the push towards sustainability and climate resilience now shaping infrastructure policy globally calls for a paradigm shift towards whole-life asset management and circular economy (CE) principles have grown signitficantly in light of macro trends such as finite materials, mounting waste, urbanization, and the climate change (Wijewickrama, 2021). Accepting these principles means considering the life span of an asset from its ideation, design, and construction to its use, maintenance, and decommissioning at the end of its life while seeking to reduce waste and improve the total value extracted from every resource used. Whole life asset management redefines infrastructure as a living system, highlighting how its financial viability, social and environmental impacts, and functionality evolve over a period of time, requiring an adaptable and forward-looking approach to risk and opportunity in the future.

However, this point of view is highly relevant in a theoretical approach, while circular economy concepts offer a practical approach to reducing waste and resource use, encouraging reuse and recycling, and procurement methods that contribute to long-term use, adaptability, and value.

A few of the advantages of using whole life asset management and circular economy principles in PPPs are reduced life cycle cost, long-term use of assets, social and economic

inclusion, and lower environmental footprints.

Contractual arrangements need to change to encourage flexibility and long-term thinking. Performance measurement needs to shift towards dynamic, inclusive, and life-cycle-oriented indicators. Examples of digital, technological and financial innovations can promote greater transparency and realign incentives including asset tokenization, smart contracts, and BIM-based tracking; however, they also make collaboration more complicated and time consuming (Reiner, Estrada, Klein, & Bernardi, 2023; Zhang, Zhong, Zhao, & Chan, 2024; Tian, Wang, Asutosh, Woo, & Adriaens, 2022).

Moreover, the shift towards whole-life and circular-oriented PPPs is not simply a technical or contractual challenge; it is fundamentally a matter of effective partnership and governance. Government sector and private sector actors must work to achieve a balance between financial gains, social goals, and environmental protection in order to manage competing interests and viewpoints over long concession periods (Stål, Manzhynski, & Bengtsson, 2024). Strong governance frameworks, teamwork, adaptability, and the capacity to change with the dynamic times and adapt to new skills are all necessary for success.

This study examines how the PPP model's circular economy ideas and whole-life asset management interact. We start by discussing the need for whole life asset management and looking at the shortcomings of PPP performance evaluations that are already being used. The usage of circular economy techniques in infrastructure, along with how circularity can be included in the operations, procurement, and design. This paper focuses on organisational and digital innovations that facilitate the changes in the finance models, data systems, and governance frameworks. We discuss the opportunities and conflicts that arise when public and private incentives are combined. At the end, we highlight the research requirements and offer an ongoing policy and implementation framework.

Literature Review

Evolution of Public-Private Partnerships

Public-private partnerships (PPPs) have developed significantly since their adoption in the 1990s, when governments joined hands with the private sector and incorporated their efficiency to provide infrastructure and public services (World Bank Group, 2008). In spite of their widespread use, traditional PPP models have been criticised for prioritising short-term delivery rather than long-term sustainability results and for constantly adopting “design, build, operate, dispose” strategies that overlook opportunities for resource recovery and life-cycle improvement (Shen et al., 2016).

Whole-Life Asset Management Approaches

The concept of whole-life asset management addresses these limitations by considering comprehensive lifecycle costs and benefits

from conception through decommissioning (Zhou & Yin, 2018). According to research, operating and maintenance expenditures are roughly 200 times higher than the initial capital investment, which frequently only makes up a small portion of overall ownership expenses (Constructing Excellence, 2015). Although there are quantifiable advantages to whole-life approaches, such as lower total cost of ownership, longer asset life, and better risk management, implementation is hampered by institutional aversion to change and fragmented data systems (Gleeds, 2022).

Circular Economy in Infrastructure

By moving from conventional linear models to regenerative systems that design out waste and maintain materials in productive use, the concepts of the circular economy provide supplementary approaches for infrastructure sustainability. Up to 79% of global greenhouse gas emissions are attributed to infrastructure, according to the Global Infrastructure Hub, underscoring the need for circularity in reaching decarbonization targets. Byers et al. (2025) point out that although practitioners recognise the great potential for repair, refurbishment, and recycling approaches, circular economy research in infrastructure has lagged behind other sectors, with practitioners mostly depending on disposal strategies.

Sustainability Performance Measurement

Performance measurement in sustainable PPPs requires advanced frameworks that balance economic, social, and environmental factors beyond the traditional metrics (Shen et al., 2016). The usefulness of current circular economy indicators for sustainability assessments is limited as they constantly concentrate on material flows while ignoring the social and economic effects.

Digital Transformation and Technology Integration

Combining BIM, IoT, and AI technologies makes digital transformation an important instrument for building sustainable PPPs (Honcharenko et al., 2021). Such developments help in data-driven decision making, maintenance and planning, and access to monitoring across asset lifecycles. BIM- IoT integration helps in the usage of systems that maximise resource usage (RICS, 2025). Automating contract execution and increasing transparency for stakeholders, the usage of digital innovations creates further opportunities to improve PPP governance.

Governance and Risk Management Frameworks

Given the critiques of unplanned PPP implementation, governance frameworks have changed. In addition to optimisation of risk transfer, effective risk management incorporates optimal allocation, which distributes risks to individuals most capable of taking them (World Bank Group, 2020). Throughout project lifecycles, engagement with stakeholders is important to strategise for various groups such as the end users,

commercial partners, and governmental organisations.

Research Gaps and Future Directions

There exist significant gaps regarding the systematic integration of whole life asset management and circular economy principles within PPP frameworks. There is a need for frameworks that integrate these methods, which help in building sustainable infrastructure.

Discussion

The study examines the shortcomings of conventional PPPs in the infrastructure sector, which usually rely on linear "design-build-operate-dispose" models that give priority to immediate delivery while usually neglecting long-term value, adaptability, and sustainable resource use. Public infrastructure projects can be made more sustainable and socially valuable by lowering lifecycle costs and waste and integrating whole life asset management and circular economy concepts into PPP frameworks. Whole life management transforms “value for money” by estimating infrastructure from design to decommissioning, considering long-term financial, social, and environmental impacts, proactive risk management, and flexibility to meet changing needs.

The paper stresses the fact that recognising these benefits depends on improved contract structures, dynamic performance metrics, digital innovation through BIM and blockchain, and joint governance over stakeholders. Upskilling institutional improvement is necessary for success, digital and financial innovations to enable transparency, enhance maintenance, and foster flexible data-driven processes. The study concludes with a strong recommendation for flexible metrics, contractive provisions, and standardised data governance in order to move from linear to regenerative PPPs that benefit the upcoming generations

Reassessing Asset Value: The Case for Whole-Life Management in PPPs

The Challenges of Linear, Short-Term PPP Models

Fundamentally, a lot of PPP projects are still trapped in a heritage "linear" mindset, assets are planned, constructed, and used for a predetermined amount of time before being returned to the government, often with little thought given to their state, adaptability, or possibility for future use. Such models frequently prioritise savings during construction or early operation at the expense of long-run utility and cost-effectiveness (Shen et al., 2016). Despite the PPP model's broad acceptance, which includes notable markets in the UK, Europe, and India, the focus on in advance financial arrangements (such as Build–Operate–Transfer or BOT structures), deferred maintenance, and a "pass-the-parcel" mentality at project handback have led to a neglect in long-term service and innovation (Demirag et al., 2011). The success of a PPP is often measured by

whether it delivers an asset on time and on budget, but these metrics offer a partial, even misleading, view of value (Liu et al., 2015).

Moving Towards a Whole-Life Asset Approach

The rationale for adopting a whole-life approach in PPPs is increasingly clear. Whole-life asset management means considering not only the initial capital outlay, but also the full spectrum of costs, risks, and opportunities that occur over an asset's lifespan: operations, routine and preventative maintenance, user experience, adaptability to new uses or technologies, and eventual decommissioning (Giglio et al., 2018).

Such an approach reframes "value for money" to encompass:

- **Long-term financial performance**: Reducing the total cost of ownership, extending asset life, and minimising expensive reactive maintenance.
- **Risk management**: Proactively addressing changing climate, technology, and demand risks over multi-decade timeframes.
- **Social and environmental impacts**: Enriching community wellbeing, health, safety, and reducing pollution and waste.

Advanced tools like asset information models, dependable maintenance, and discounted cash flow methods can show the hidden costs of putting off maintenance and the benefits of planned interventions. Research demonstrates that an effective course of life of asset management results in measurable monetary benefits, especially for complex, expensive infrastructure like water systems, rail networks, and highways (Giglio et al., 2018).

Realigning Risk and Reward throughout the Asset Lifespan

A whole-life approach necessitates the continual re-examination of how risks (such as operational failures, obsolescence, or end-of-life decommissioning) and rewards (profit, fee payments, cost savings) are distributed between partners as the asset ages and as conditions change (Zhang & Chen, 2013). Zhang and Chen's (2013) prestigious four-stage framework describes how PPP contracts can be structured to account for public service requirements, risks and uncertainties, and evolving competitive dynamics. By incorporating phase-specific competition elements and performance review gateways, concessions can be adjusted, renegotiated, or even retendered, ensuring continuous performance improvement while protecting the public interest. Overall, whole-life management pushes both the public and private sectors beyond transactional thinking. For assets to stay up with changing usage expectations, technological advancements, and regulatory standards across their decades-long lifespans, it is essential to provide contract flexibility and dynamic performance criteria.

Establishing Objectives: Sustainability and Performance Evaluation

Triple Bottom Line: Going Beyond Finance

The argument for sustainable public-private partnerships (PPPs) is now widely accepted in the literature. Infrastructure has effects that go beyond the economy. It affects health, social equality, inclusion, land value, and, most importantly, the degradation or restoration of the environment (Shen et al., 2016).

Shen et al. (2016) provide a performance appraisal that balances economic, social, and environmental factors in order to embed sustainability in evaluation. For instance, indicators for resource efficiency, pollution, waste creation, and community satisfaction should be included in appraisals along with cost and revenue measures. This wide view compels decision-makers to acknowledge that the true "value" of an infrastructure asset lies in its capacity to produce favourable, equitable results in a variety of areas over the course of its existence.

The Life-Cycle Performance Prism

To take into consideration the complex and dynamic nature of PPP infrastructure projects, the "performance prism" and other traditional performance frameworks have been adjusted. By assigning important indicators to stakeholders (citizens, operators, and investors) and asset lifecycle phases (planning, design, operation, and handback), Liu et al. (2015) expand on this methodology. This allows for more precise monitoring and identifies when specific priorities become more important. A dynamised performance measurement system, one that records data at intervals, allowing for review and recalibration, can help avoid the "fire-and-forget" syndrome that undermines sustainability in many PPPs. An asset that was first designed for basic vehicle travel, for example, might be reassessed after ten years to give priority to digital connectivity, active transportation, or flood resilience, all of which call for distinct metrics and investment objectives (Liu et al., 2015).

Accepting Uncertainty: Qualitative and Adaptive Methods

The use of modern approaches like scenario-based system dynamics modelling and cloud-based stakeholder weightings has been led by the challenges of evaluating performance in the face of competing objectives and ambiguous deadlines. Although long-term, multi-party PPPs involve uncertainty (Wang et al., 2023), they argue that these methods can help improve accountability by converting diverse stakeholder perspectives and expert qualitative judgments into consistent assessments.

A scenario-based analysis, for example, can help stakeholders better understand how changes to maintenance budgets, legal requirements, or climate risk may impact asset performance, aiding in proactive planning and adaptive management (Wang et al., 2023).

Closing the Loop: Circular Economy Principles in PPPs

From Linear to Circular: The Significance of Circularity

Linear design and operation models are under growing scrutiny for their environmental externalities and squandered resource value. The world is shifting from resource-intensive, waste-generating pipelines of raw materials to production, use and disposal “at scale" to models where resources cycle repeatedly with the goal of “designing out” waste, emissions, and unnecessary consumption (Wijewickrama, 2021; Akomea-Frimpong et al., 2022).

The construction industry, for instance, is one of the biggest generators of waste and embodies a massive proportion of the world’s extracted resources. Transitioning from a linear to a circular economy in construction and infrastructure PPPs means:

- Designing for deconstruction and reuse (components can be retrieved intact and reused in new projects)
- incorporating "material passports" into electronic monitoring platforms to record the value, composition, and longevity of construction components (Reiner et al., 2023)
- Creating business models where value is retained and shared not just in use, but also through recovery, rental, or secondary markets at the end of life.
- Establishing obligations and economic incentives for recycling, refurbishing, and flowing use within contractual agreements.

Korhonen, Honkasalo, and Seppälä (2018) describe the circular economy as fundamentally altering the economic model by turning what was once considered waste into a continuous flow of value, aligning economic incentives with environmental preservation.

Implementing Circularity into PPP Contracts

There is still a big disconnect between theory and practice, even with CE's growing popularity. Few PPP contracts currently in use include commitments or incentives for material recovery, reuse, or secondary use business models, and the majority of them don't outline what should happen when a project is disposed of or decommissioned (Akomea-Frimpong et al., 2022). In response, guidelines for integrating CE principles into PPPs have been developed by the UNECE (United Nations Economic Commission for Europe, 2022). Indicators for life cycle performance, procedures for returning products, and management for recycled materials are some of their proposals, which stress the significance of integrating circularity into the foundational framework of project management, material procurement, and infrastructure design. Rather than considering waste reduction as an optional extra, these provisions become considerably more effective when linked to

financing models that incentivise or penalise matrix performance.

Learning and Making Compromises: Navigating Conflicting Priorities

Actors in the public and private sectors naturally become tense while switching from linear to circular models. Private companies usually place a higher importance on profitability, practical efficiency, and acceptable risk than governments and communities, which often place a higher value on social benefits and environmental protection (Stål et al., 2024). However, as observed in recent case studies in Sweden, disagreement and negotiation should not halt progress. Over long concession periods often prolonging to two or three decades, collaborative PPPs repeatedly course through stages of conflict, compromise, and mutual alteration. In exchange for more assertive recycling or reuse targets, governments sometimes offer extended concessions or separate secondary market earnings. In other cases, private sector enterprises will comply with strict environmental standards if regulatory agencies promise to reduce red tape or speed up approval processes (Stål et al., 2024).

Instead of viewing it as signs of failure, these generally repeated processes often spark innovation and institutional learning, leading to mixed corporate models that combine public value goals with the primary motive of profit-seeking.

Principles from the Development of the Circular Economy

The importance of diversified, multi-stakeholder collaboration is highlighted by the historical development of CE principles. Contrary to a strict belief, the CE movement was the result of extensive collaboration between private companies, non-governmental organisations, regulators, and researchers to develop diverse and environmentally friendly approaches to waste reduction and value creation (Albareda Vivó & Kimpimäki, 2023). Four procedures - pragmatic translation, collective definition, amplification through demonstration, and institutional support describe how early collaborations and collective governance gave circular initiatives credibility and real-world application. This indicates that in PPPs, circular acquisition models and contractual conditions will be extensively acceptable and long-lasting when developed through networked and well-connected administration, learning, and negotiation; early backing is crucial for broader adoption (Albareda Vivó & Kimpimäki, 2023).

Enablers: Digital Innovations and Financial Mechanisms

Digital Transformation: BIM, IoT, Data, and Smart Management

Digital technologies, such as building information modelling (BIM), the Internet of Things (IoT), artificial intelligence (AI), and real-time location systems, are changing the way PPPs manage assets and flow of

resources over their life cycle (Reiner et al., 2023; Zhang et al., 2024). These innovations offer asset inventories, predict the need for maintenance, material optimisation, and usage improvements. BIM-based material and digital tagging help project operators to plan the sources, use, and performance of asset elements, making it easier to recycle, reuse, or reclaim materials at the end of a project. Similarly, IoT sensors used in infrastructure monitor how they are performing to detect if they are getting worn out and their conditions. This allows for upkeep before a costly breakdown, saving money and unexpected damage. Digital twins, a virtual replica of physical assets, allow operators to test how to use, fix, or change the asset in a safe and virtual setting, leading to cost effectiveness and more dependable management (Zhang et al., 2024). Using technology to buy goods and services, with strict management and clear rules, lets organisations see exactly what is happening and make better, fact-based choices that enhance both profits and how well they protect the environment. But new concerns are brought about by technological improvements. Public sector workers, contractors, and facility managers must receive training in order to integrate these tools into PPPs because their technological ability and skill can differ greatly (Zhang et al., 2024).

Automation, Robotics, and Lifecycle Cost Optimisation

Automation helps PPPs work better and last longer by making them more efficient. Automated creation and construction decrease waste of resources, increase project consistency, and limit workers' vulnerability to unsafe spots (Pellegrini, Mülhardt, Rossi, & Milano, 2021). Robotics, augmented reality/virtual reality (AR/VR), and sensor networks operate together to determine early detection of system pressure, saving energy and water, and extending the life of systems through detailed maintenance. Such improvements have a significant effect on the circularity and economic usefulness of assets. Decreased downtime, minimised rework, and efficient planning ultimately mean costing less money over the entire life of resources. Automated tracking and operating resources make it easier to meet circular economy goals and prove that these goals are actually being met. However, to unlock most of these benefits, government rules and procurement methods in PPPs must be modified to adjust to new ways of operating assets and business models (Pellegrini et al., 2021).

Tokenisation, Blockchain, and Inclusive Financing

In recent years, emerging financial technologies such as blockchain and asset tokenisation have begun to transform infrastructure investment. Blockchain's transparency and ability to not be changed or deleted once created breaks up the cost of infrastructure assets, allowing fractional ownership among small investors and growing the funding base for PPP projects (Tian et al., 2022). Smart contracts (self-

executing agreements with terms encoded on the blockchain) enable performance metrics and financial incentives to be hardwired into project operation, increasing trust among stakeholders and improving accountability.

In some sectors, like energy, case studies reveal that tokenisation lets different types of investors chip in money into projects by dividing assets such as a solar farm into smaller digital tokens, making investors participate in the long run and funding lifecycle upgrades and CE initiatives that traditional funding might overlook (Tian et al., 2022). Such platforms may also include explicit incentives for circular practice: for instance, investors can be rewarded based on quantities of recovered materials or reductions in emissions, measurable though transparent, auditable digital records. Tokenisation and decentralised finance add a layer of innovation to what has traditionally been a slow-moving, capital-intensive domain, but the scalability and regulatory integration of such models within PPPs remains an area for further trial and refinement.

Urban Data as a Resource: Creating Smart, Circular Cities

In order to enhance infrastructure planning and provide sustainable, data-driven services, smart city initiatives are increasingly depending on massive streams of urban data on transportation flows, energy consumption, waste generation, and social preferences (Romualdo-Suzuki & Finkelstein, 2020). PPPs are essential to the implementation of the systems and technologies that gather, store, and process this data. However, merely accumulating technical capability is not enough. The biggest challenge is connecting technology to stakeholder value, governance, and long-term community goals (Romualdo‑Suzuki & Finkelstein, 2020). In order for the cities to be sustainable, they must use citizen-centric techniques and a coordinated system for managing data that supports both smart and circular infrastructure development. Treating city-level data as a durable public utility rather than a private asset underpins the shared decision-making and innovation necessary for system-wide CE transitions.

Institutional and Partnership Dynamics in Circular, Whole-Life PPPs

Changing Public Sector Responsibilities

For PPPs to offer a cyclical and whole-life value, rather than just focusing on initial building and development of infrastructure, public authorities must take a more active role and have a hands-on approach, and take on a greater variety of responsibilities. Governments are in a unique position to create laws, performance standards, and procurement procedures for a circular economy (Owojori & Okoro, 2022). This includes classical oversight and enforcement, direct support through grants and subsidies, training, standardised documentation, and the cultivation of statutory authorities capable of industry coordination.

Consistent progress over extended project horizons can be ensured by regular, institutionally required sector evaluations in conjunction with HR and procurement policies linked to industrial growth objectives and skills development. Additionally, sectoral "circularity toolkits" can be updated and developed to assist in aligning expectations and common practices across projects and regions (UNECE, 2022).

Private Sector Adaptation and Transparency

For their part, private firms participating in PPPs must go beyond compliance, contributing proactively to the spreading of circular business models, technological innovation, and lifecycle data transparency (Owojori & Okoro, 2022). Initiatives such as simplification and standardisation of contracts, sharing of best practices, and full disclosure of material and performance data are essential.

Private actors have a critical role in translating high-level sustainability and circularity requirements into real-world design, engineering, and operational processes. Meeting with public authorities before concluding a bid helps make sure that practical ideas are incorporated in the contract terms, instead of non-binding commitments (Owojori & Erasmus, 2025).

Partnership Quality: Trust, Adaptation, and Mutual Learning

The success of major PPPs depends greatly on the quality of the partnerships because of their lengthy durations and high levels of intricacy. Public sector capability and input, private entity capability and input, and partnership quality are the five factors that support PPP sustainability when viewed through the lens of system dynamics (Wang et al., 2023). When both partners are able to communicate freely, are adaptable, and cooperate to overcome obstacles as circumstances change, the partnership is strong and adaptive. Stakeholder feedback mechanisms, collaborative learning cycles, and iterative scenario analyses all help in identifying issues early on and serve as the basis for ongoing cooperation and adaptation. In successful collaborations, mutual trust ensures honesty, which in turn produces creativity. Additionally, resolving issues as a group enhances the system and generates favourable feedback (Wang et al., 2023).

Standardisation and Ongoing Performance Improvement

Despite occasionally being criticised as "one-size-fits-all," efforts to standardise contracts, performance metrics, and reporting structures can, in the right circumstances, reduce transaction costs, facilitate cross-project learning, and promote healthy competition (Verhoest, Petersen, Scherrer, & Soecipto, 2015). To stay up with CE technology, changing market structures, and societal expectations, rules and guidelines must be adaptable and intended to be updated frequently.

Tensions and Compromise: Coevolution's Reality

Past and current researches reveal that working together on PPPs can be difficult, particularly when switching from traditional linear models to experimental circular models. Due to differences in preferences, expectations, and perceived risks, uncertainties are inevitable (Stal et al., 2024). However, these uncertainties can be reformed as a motivation for innovation rather than a barrier when partnership arrangements are strong, inclusive, and capable of learning. These dynamics demonstrate the flexible, co-evolutionary nature of successful PPP implementation in the age of the circular economy, as the next rounds of negotiation result in hybrid, context-sensitive approaches (Albareda Vivo & Kimpimaki, 2023).

Metrics and Measurement: Addressing Gaps and Raising Standards

The Challenge of Circularity Metrics

The creation of trustworthy and relevant metrics is a constant problem in the operationalisation of circular PPPs. Most of the CE metrics currently in use focus on material flow analysis, measuring the number of tons that are recycled, reused, or kept out of landfills (Corona, Shen, Reike, Carreón, & Worrell, 2019). Despite being an important element, this overlooks the broader social and economic effects, like job creation, inclusion of communities, innovation, and resilience enhancements. Additionally, with fragmented, non-standardised methods in circulation, comparability across projects and contexts suffers, making it difficult to evaluate progress or transfer best practices. Circular metrics should be thorough, including social, economic, and environmental indicators, measured throughout an asset's life, ensuring that everything is considered (Corona et al., 2019).

Comprehensive Lifecycle Metrics for Real Progress

A more thorough set of metrics should include:

- **Resource Intensity:** Energy, water, and material inputs per unit of service provided
- **Waste Generation and Recovery:** Tons recycled, reused, or repurposed compared to baseline
- **Greenhouse Gas Emissions:** Lifecycle carbon footprint
- **Social Outcomes:** Accessibility, affordability, job creation, community satisfaction
- **Economic Indicators:** Lifecycle costs, cost avoidance, value generated from circular activities
- **Adaptability and Resilience:** Capacity to respond to climate, market, or demographic shifts

Building, testing, and institutionalising such metrics, as part of standard reporting and

procurement documentation, remains a critical task for both researchers and practitioners (Corona et al., 2019).

Case Studies and Practical Illustrations

Circular PPPs in Waste Management and Resource Recovery

One of the most visible applications of circular thinking in PPPs is in the domain of waste management. As Owojori and Erasmus (2025) discuss, new PPP models are being deployed to build, operate, and upgrade waste reduction, recycling, and resource recovery systems that serve as key "green infrastructure." These collaborations provide venues for the interaction of circular business models, technology innovation (such as waste sorting sensor networks), and community involvement to turn "waste" into useful urban resources.

Digital Infrastructure for Circular Construction

Another rapidly evolving area is digital asset management in the construction sector. Real-time tracking, material passports, and BIM are some of the technologies that have begun to enable the widespread use of circular techniques (Reiner et al., 2023). Construction projects can improve logistics, reduce redundant materials, facilitate effective repair, and plan for component recovery at the end of use by digitally tracking component histories. Circular targets are much more likely to be met when these tools are incorporated into PPP contracts and governance frameworks.

Smart Cities: Integrating Data, Governance, and Circular Value

In the urban context, the convergence of data strategies and circular economy objectives has enormous potential but is not without its challenges. Romualdo‑Suzuki and Finkelstein (2020) present cases in smart city development where a technology-first strategy overlooked crucial governance and stakeholder problems, limiting the range and influence of circular applications. City-scale circular solutions are only possible and equitable when urban data is regarded as infrastructure for everyone (with powerful privacy controls, citizen participation, and management connected to actual value creation).

Priority Research and Policy Gaps

Several critical areas require further exploration and policy development:

1. **Standardized, Lifecycle-Based Circularity Metrics:** incorporating social and economic results in addition to material flows.
2. **Contractual Clauses for End-of-Life Circularity:** Defining obligations and incentives for decommissioning, repurposing, and resource recovery within contracts.
3. **Adaptive Contracting and "Evolution Clauses":** Embedding flexibility to respond to technological, environmental, or market changes over decades.

4. **Capacity Building and Skills Development:** Strengthening digital, managerial, and collaborative skills across sectors to maximise circular and whole-life outcomes.

5. **Urban Data Governance:** Balancing openness and privacy to enable city-scale, distributed circular value chains.

Conclusion

Making a Path for Circular, Whole-Life PPPs: The separation of infrastructure development from resource insufficiency and the modification of waste and obsolescence into new forms of value creation stands as a defining challenge for twenty-first-century infrastructure policy and practice. By incorporating whole-life asset management and circular economy principles into PPPs, the public and private sectors can arrange their incentives to construct infrastructure that is sustainable, flexible, and conscious of future societal needs.

Accomplishing this synthesis is complicated. It requires a blend of new ideas in contracts, technology to help things run smoothly, strict and thorough tracking of results, strong partner governance, and the ability for continuous learning and adaptation. Extended asset life, decreased lifecycle costs, environmental management, and communities that benefit from infrastructure as a regenerative force are a few of the many potential benefits, as the cases and research analysed show. Moving towards adaptable, flexible, and statistic-based frameworks that support this new understanding of PPPs as platforms for creating whole life, circular value for society rather than just projects is both morally and practically necessary as professionals, academics, and policymakers continue to develop and test these approaches.

References

Albareda Vivo, L., & Kimpimaki, J. P. (2023). *How did it come to be? Circular economy as collective stakeholder action.* In Stakeholder engagement in a sustainable circular economy: Theoretical and practical perspectives (pp. 19–55). Springer.

Akomea-Frimpong, I., Jin, X., & Osei-Kyei, R. (2022). Mapping studies on sustainability in the performance measurement of public–private partnership projects: A systematic review. *Sustainability, 14*(12), 7174. https://doi.org/10.3390/su14127174

Campbell, H. (2001). Planning ethics and redistribution. *Town Planning Review, 72*(2), 187–206.

Corona, B., Shen, L., Reike, D., Carreon, J. R., & Worrell, E. (2019). Towards sustainable development through the circular economy: A review and critical

assessment on current circularity metrics. *Resources, Conservation and Recycling, 151,* 104498. https://doi.org/10.1016/j.resconrec.2019.104498

Demirag, I., Khadaroo, I., Stapleton, P., & Stevenson, C. (2011). Risks and the financing of public–private partnership projects: Perspectives from financiers. *British Accounting Review, 43*(4), 294–310. https://doi.org/10.1016/j.bar.2011.08.006

Giglio, J. M., Friar, J. H., & Crittenden, W. F. (2018). Integrating life-cycle asset management in the public sector. *Business Horizons, 61*(4), 511–519.

Khanom, N. A. (2010). Conceptual issues in defining public–private partnerships (PPPs). *International Review of Business Research Papers, 6*(2), 150–163.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics, 143,* 37–46.

Liu, J., Love, P. E. D., Davis, P. R., Smith, J., & Regan, M. (2015). Conceptual framework for the performance measurement of public–private partnerships. *Journal of Infrastructure Systems, 21*(1), 04014023.

Owojori, O. M., & Erasmus, L. J. (2025). Public–private partnership risk governance and performance outcomes. *Journal of Public Procurement,* Advance online publication.

Owojori, O. M., & Okoro, C. (2022). Risk allocation practices in infrastructure public–private partnerships. *International Journal of Construction Management, 22*(8), 1453–1465.

Pellegrini, A., Mülhardt, L., Rossi, A., & Milano, M. (2021). Decision-support systems for sustainable infrastructure management. *Sustainable Cities and Society, 68,* 102776.

Reiner, M. L., Estrada, S., Klein, J., & Bernardi, S. (2023). Sustainable investment decision-making in infrastructure projects. *Journal of Sustainable Finance & Investment, 13*(2), 456–472.

RICS. (2025). *Global infrastructure standards and professional guidance*. Royal Institution of Chartered Surveyors.

Romualdo-Suzuki, L., & Finkelstein, A. (2020). Stakeholder governance in sustainable infrastructure development. *Journal of Business Ethics, 165*(3), 567–584.

Shen, L. Y., Tam, V. W. Y., Gan, L., Ye, K., & Zhao, Z. (2016). Improving sustainability performance of construction projects through public–private partnerships. *Journal of Cleaner Production, 112,* 423–431.

Stål, H. I., Manzhynski, S., & Bengtsson, M. (2024). Circular business models and ecosystem collaboration. *Business Strategy and the Environment, 33*(1), 211–225.

Tian, Y., Wang, C., Asutosh, A., Woo, J., & Adriaens, P. (2022). Circular economy and infrastructure sustainability transitions. Resources, *Conservation and Recycling, 180,* 106172.

United Nations Economic Commission for Europe. (2022). Public–private partnerships and sustainable development goals implementation guide. UNECE.

Verhoest, K., Petersen, O. H., Scherrer, W., & Soecipto, R. M. (2015). How do governments support the development of public–private partnerships? Infrastructure governance review. *Public Management Review, 17*(3), 384–404.

Wang, X., Zhang, Q., Wang, D., Liu, H. J., & Sing, M. C. P. (2023). Risk allocation mechanisms in infrastructure PPP projects. *International Journal of Project Management, 41*(4), 489–503.

Wijewickrama, M. K. C. S. (2021). Critical success factors of public–private partnership infrastructure projects. *Built Environment Project and Asset Management, 11*(3), 401–417.

World Bank Group. (2008). Public–private partnership handbook. World Bank.

World Bank Group. (2020). Procuring infrastructure public–private partner ships report. World Bank.

Zhang, S., Zhong, K., Zhao, X., & Chan, A. P. C. (2024). Sustainable performance evaluation of infrastructure PPP projects. *Journal of Construction Engineering and Management, 150*(2), 04023102.

Zhang, X., & Chen, S. (2013). A systematic framework for infrastructure public–private partnership decision-making. *International Journal of Project Management, 31*(3), 401–415.

To cite this article

****

Muskan Sehgal, Sejal Sagar, & Pranav Vaishnav. (2025). Whole-Life Asset Management and Circular Economy Principles for Public-Private Partnerships (PPPs): Towards Sustainable Infrastructure. *Sparkling International Journal of Multidisciplinary Research Studies, 8*(4), 40-57.

****

ABOUT THE AUTHORS

Muskan Sehgal *is a student of Commerce at CHRIST (Deemed to be University), Bangalore, Karnataka, India, with academic training and practical exposure in finance and financial analysis. Her experience includes internships focused on corporate treasury, financial analysis, and investment analysis, providing her with hands-on exposure to structured reporting and analytical evaluation. She has a strong interest in equity research and financial analysis and aims to apply analytical frameworks to research-oriented and real-world financial contexts.*

Sejal Sagar *is a student of Commerce at CHRIST (Deemed to be University), Bangalore, Karnataka, India, with a strong foundation in finance, accounting, and business management. Her experience includes internships focused on operational workflows of the finance and accounts department. She actively engages in both academic and practical learning, aiming to build a professional career in the field of finance.*

Pranav Vaishnav *is pursuing commerce at CHRIST (Deemed to be University), Bangalore, Karnataka, India. His interests span financial analysis, business strategy, and market-oriented decision-making, and he demonstrates a structured and analytical approach to real-world business challenges. Pranav is motivated to build a career that not only fosters professional growth but also contributes positively to society through responsible and impactful work.*

****