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The Evolution of Minimum Revenue Guarantees (MRGs) in PPP Infrastructure Investment

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Abstract

This study investigates the evolution of minimum revenue guarantees (MRGs) in public-private partnership (PPP) infrastructure investment, tracing their development from basic risk mitigation instruments to dynamic, strategically optimized, and sustainability oriented financial mechanisms. A qualitative research design was employed using systematic thematic synthesis of peer reviewed literature indexed in Scopus and Web of Science (WoS) up to February 2026. The review screened 415 records and identified 44 eligible articles for analysis, comprising 5 studies published up to 2010, 8 during 2011 to 2015, 16 during 2016 to 2020, and 15 during 2021 to 2026. The findings reveal four evolutionary phases characterized by advances in real options valuation, risk sharing optimization, game theoretic contract design, adaptive profit distribution, and sustainability focused applications. The study proposes a unified conceptual framework consisting of three interrelated dimensions: strategic and game theoretic contract optimization, adaptive and performance linked guarantee mechanisms, and sustainability-oriented sector specific financial structuring. The framework contributes to theory by integrating historical and contemporary developments into a comprehensive roadmap for MRG design. Practically, it provides guidance for policymakers and practitioners seeking to balance fiscal sustainability, investor incentives, and long-term infrastructure resilience. The study is limited by its reliance on qualitative literature synthesis and highlights opportunities for future empirical, quantitative, and digital finance research to further refine adaptive MRG frameworks.

Keywords

Infrastructure, investment, minimum revenue guarantee, PPP, risk management

INTRODUCTION

Infrastructure investment increasingly relies on public–private partnerships (PPPs) as a mechanism to mobilize private capital for large-scale projects [1-3]. While PPPs offer opportunities to share risks between the public and private sectors, they also introduce complex financial uncertainties, particularly regarding revenue generation [4]. One financial instrument that has emerged to address this challenge is the minimum revenue guarantee (MRG), a contractual assurance provided by the government to protect private investors against insufficient revenue realization [5, 6]. The adoption of PPPs is particularly relevant in infrastructure sectors characterized by demand volatility and long concession periods, such as transportation, energy, and water treatment projects [7-10].

The historical development of MRGs reflects the need to balance public and private stakeholder interests while ensuring project viability. Early applications of MRGs primarily focused on basic risk mitigation strategies in build, operate, and transfer (BOT) concessions, providing private operators with a guaranteed minimum cash flow to reduce exposure to demand fluctuations [11, 12]. Over time, MRG structures have evolved to incorporate sophisticated financial tools, including revenue caps, contingent finance support, and real options, to optimize risk-sharing arrangements [13, 14]. These innovations underscore the growing recognition of MRGs not only as risk management instruments but also as mechanisms to enhance strategic flexibility in project design and financial structuring [15, 16].

Despite widespread adoption, practical implementation of MRGs remains challenging. The valuation of revenue guarantees under uncertain demand conditions is complex, often requiring stochastic modeling or real options analysis to accurately capture risk profiles [17-19]. The design of optimal MRG levels must also consider the trade-offs between government fiscal exposure and private investor incentives. Overly generous guarantees may create moral hazard, while conservative guarantees may discourage investment [20, 21]. Recent studies emphasize the importance of incorporating capacity constraints and dynamic profit-sharing mechanisms into

MRG structures to reflect operational realities in complex infrastructure projects [22, 23].

A notable development in MRG evolution is the application of strategic and game-theoretic approaches to support decision-making under risk-sharing arrangements. Researchers have employed option-based frameworks and multi-stage game models to evaluate the interplay between government guarantees and private investment strategies, providing insights into optimal contract design under uncertainty [16, 24]. These approaches demonstrate that MRGs are no longer static contractual clauses but are increasingly embedded in adaptive PPP frameworks that account for exogenous shocks, demand volatility, and project renegotiation potential [25, 26].

The integration of MRGs into sustainable infrastructure development has also attracted scholarly attention. As PPP projects increasingly aim for socially and environmentally sensitive outcomes, MRGs have been incorporated into financial structures that align investor incentives with broader policy objectives, including renewable energy deployment, resilient transportation networks, and off-grid electrification [6, 27]. By linking revenue guarantees to performance metrics and real options, governments can establish frameworks that mitigate financial risk while promoting long-term value creation and strategic investment decisions [28, 29].

Despite the breadth of literature on MRGs, significant gaps remain. Few studies provide comprehensive analyses of how MRG structures have evolved across multiple decades and project types, capturing both technical advancements and strategic adaptations. Conceptual frameworks that integrate historical evolution with contemporary financial instruments and policy mechanisms are scarce, limiting the ability of policymakers and practitioners to design MRGs that are effective in risk mitigation and adaptive to changing economic, technological, and regulatory conditions.

Given these considerations, this study examines the evolution of MRGs in PPP infrastructure investment projects. The research objectives are:

- RO1: To identify the development of MRG structures in infrastructure projects, highlighting advancements and applications across multiple decades up to 2026.
- RO2: To develop a conceptual framework that synthesizes historical and contemporary insights for practical implementation in PPP infrastructure investment.

RESEARCH SIGNIFICANCE

This study contributes to the literature on PPP infrastructure finance by examining the evolution of MRGs as a risk sharing mechanism between governments and private investors. By synthesizing historical developments and contemporary financial approaches, the study demonstrates how MRGs have evolved from basic demand risk mitigation instruments into more adaptive mechanisms that support strategic contract design. The proposed conceptual framework offers practical guidance for policymakers and practitioners in structuring MRG arrangements that balance investor protection with government fiscal sustainability in long term infrastructure projects.

METHODOLOGY

A qualitative research design was adopted to explore both the historical evolution and contemporary applications of MRGs. This approach is particularly suitable for an in-depth investigation of MRG mechanisms. The study emphasizes interpretive analysis of documented academic literature to identify thematic trends and innovations in MRG structures across multiple sectors and historical periods. The qualitative framework enables the integration of multiple perspectives [30, 31], including government policy and private sector investment behavior.

A. DATA COLLECTION

Data were collected through a systematic review of peer reviewed journal articles related to MRGs and PPP infrastructure projects [32-36]. The search was conducted in the Scopus and Web of Science (WoS) databases on February 5, 2026. To ensure transparency and reproducibility, the search protocol is presented in Table 1.

The initial search yielded 415 records, comprising 194 records from Scopus and 221 records from WoS. A multistage screening process was then conducted. First, records that did not meet the language and document type criteria were removed. This stage excluded 77 records from Scopus and 61 records from WoS, leaving 277 records for further assessment.

Second, titles, abstracts, and keywords were screened to evaluate their relevance to MRG applications in infrastructure investment. During this stage, duplicate records identified across the two databases and studies not directly addressing MRGs in infrastructure projects were excluded. A total of 233 records were removed. Consequently, 44 articles were retained for qualitative analysis.

The final sample represents approximately 10.6 percent of the total records initially identified (44 of 415 records). Table 2 presents the article selection process. The temporal distribution of the included studies consists of 15 articles published during 2021–2026, 16 articles during 2016–2020, 8 articles during 2011–2015, and 5 articles published up to 2010. This distribution provides a comprehensive basis for examining the evolution of MRG research across multiple decades.

B. DATA ANALYSIS

Thematic analysis was employed to synthesize the collected data [37, 38]. Key concepts, practices, and patterns related to MRG structures were systematically coded and organized into categories. These categories were further grouped into overarching themes [36, 39]. Thematic synthesis across multiple decades up to 2026 facilitated the development of a conceptual framework that integrates historical insights with contemporary innovations, providing practical guidance for PPP practitioners and policymakers.

Table 1. Search Strategy and Protocol (Source: Authors own work, 2026)

Item	Description
Databases	Scopus and Web of Science (WoS)
Search date	February 5, 2026
Search string	"Minimum revenue guarantee" OR "minimum revenue guarantees"
Search fields	Title, Abstract, and Keywords
Document type	Peer reviewed journal articles
Language	English
Time period	Database inception to February 2026
Excluded document types	Conference proceedings, book chapters, books, editorials, notes, and review articles not directly related to infrastructure investment
Subject focus	Minimum revenue guarantees in PPP and infrastructure investment projects

Table 2. Selection Process (Source: Authors own work, 2026)

Selection Process	Scopus	WoS	Total
Records identified through database search	194	221	415
Records excluded based on language and document type criteria	77	61	138
Records remaining for screening	117	160	277
Records excluded after title, abstract, and keyword screening, including duplicates and irrelevant studies			233
Final articles included in qualitative analysis			44
Inclusion percentage			10.6%

RESULTS AND DISCUSSIONS

A. EVOLUTION OF MINIMUM REVENUE GUARANTEES UP TO 2010

The early evolution of minimum revenue guarantees in infrastructure investment up to 2010 reflects a transition from static contractual protection toward analytically grounded financial engineering. During this period, the literature concentrated on valuing minimum revenue guarantees within build operate transfer schemes, particularly in transportation infrastructure. Scholars emphasized the need to quantify government contingent liabilities, assess private sector downside protection, and incorporate managerial flexibility into contract design. The five foundational studies published between 2006 and 2010 demonstrate three dominant thematic directions: option-based valuation of guarantees, integration of minimum revenue guarantees with complementary contractual mechanisms, and advanced stochastic modeling of revenue uncertainty. Table 3 summarizes the thematic synthesis derived from these studies.

The first theme, real options valuation of minimum revenue guarantees, demonstrates a conceptual shift from viewing guarantees as fixed contractual clauses toward interpreting them as financial options embedded within concession agreements. Huang and Chou [11] valued minimum revenue guarantees jointly with the option to abandon, emphasizing the importance of downside protection and managerial flexibility in build operate transfer projects. Similarly, Chiara, et al. [40] developed a multiple exercise real options framework to capture staged decision making under uncertainty, while Chiara and Garvin [14] conceptualized minimum revenue guarantees as instruments for mitigating transportation revenue risk through embedded financial options. Collectively, these studies established the theoretical foundation for integrating real options analysis into infrastructure finance.

The second theme concerns contractual design and structured risk sharing. Jun [41] advanced the literature by examining combined agreements that integrate minimum revenue guarantees with revenue caps, thereby introducing symmetric risk allocation between the public and private sectors. This approach addressed concerns regarding excessive fiscal exposure and moral hazard by limiting upside returns while preserving downside protection. Huang and Chou [11] also highlighted the fiscal implications of guarantees, reinforcing the importance of quantifying contingent liabilities. These contributions marked an early recognition that effective minimum revenue guarantee design requires balanced incentives and transparent risk allocation within concession contracts.

The third theme reflects methodological advancement through stochastic and simulation-based modeling. Zhang, et al. [42] introduced jump diffusion processes to represent abrupt demand shocks and discontinuities in revenue streams, thereby improving the realism of option valuation in infrastructure projects. Their modeling approach extended earlier valuation techniques by incorporating stochastic volatility and probabilistic cash flow paths. When combined with simulation-based methods discussed by Huang and Chou [11] and the option pricing structures proposed by Chiara, et al. [40], this body of work demonstrates a progressive refinement of analytical tools for assessing minimum revenue guarantees under uncertainty.

Thus, the literature up to 2010 conceptualized minimum revenue guarantees primarily as option-based risk mitigation instruments within build operate transfer concessions, while gradually incorporating structured contractual mechanisms and advanced stochastic modeling. These foundational developments established the analytical and contractual basis for the more sophisticated strategic and adaptive frameworks that emerged in subsequent decades

Table 3. Thematic Synthesis of MRG Evolution up to 2010 (Source: Authors own work, 2026)

Thematic	Category	Coding
Real Options Valuation of MRG	Option to abandon in BOT projects	Downside risk protection; abandonment trigger value; project termination flexibility; salvage value consideration; contingent claim interpretation
	Multiple exercise real options	Staged investment flexibility; compound option structure; exercise timing strategy; valuation under uncertainty; infrastructure specific option modeling
	Revenue risk mitigation through options	Demand volatility hedging; flexible concession design; embedded financial options; probabilistic revenue streams; public support valuation
Contractual Design and Risk Sharing	Combined MRG and revenue cap agreements	Symmetric risk sharing; government fiscal exposure control; capped upside returns; balanced incentive structure; hybrid guarantee contracts
	Allocation of contingent liabilities	Public sector guarantee cost; fiscal sustainability assessment; risk transfer efficiency; renegotiation potential; contractual transparency
	Incentive compatibility mechanisms	Moral hazard mitigation; operator effort alignment; profit sharing logic; balanced concession terms; risk allocation clarity
Advanced Stochastic Modeling	Jump diffusion revenue modeling	Sudden demand shocks; stochastic volatility; probabilistic cash flow simulation; discontinuous revenue paths; risk adjusted valuation
	Simulation based option pricing	Monte Carlo simulation; path dependent valuation; uncertainty calibration; quantitative decision support; model sensitivity analysis
	Dynamic uncertainty representation	Long term concession modeling; revenue distribution estimation; infrastructure demand fluctuation; adaptive financial structuring; analytical risk measurement

B. EVOLUTION OF MINIMUM REVENUE GUARANTEES (2011–2015)

The period from 2011 to 2015 represents a phase of consolidation and formalization in the evolution of minimum revenue guarantees in PPP infrastructure projects. Building on the option based and stochastic valuation approaches developed prior to 2010, the literature during this period increasingly emphasized optimal contract design, fiscal efficiency, and incentive alignment within structured analytical frameworks. Scholars strengthened the theoretical foundation of minimum revenue guarantees by integrating public finance theory, principal agent modeling, and Pareto optimal optimization techniques. Across the eight selected studies, three dominant thematic directions emerge: public finance rationalization of guarantees, optimization of guarantee and revenue sharing structures, and risk adjusted valuation methodologies for transportation and utility projects. Table 4 presents the thematic synthesis for this period.

The first theme concerns the strengthening of the public finance foundation of minimum revenue guarantees. Engel, Fischer, and Galetovic (2013) conceptualize PPP guarantees within a broader fiscal framework, emphasizing that government support mechanisms must be evaluated in terms of value for money, contingent liabilities, and risk transfer efficiency. Their analysis underscores the importance of avoiding fiscal illusion and transparently accounting for government obligations. Complementing this perspective, Rocha Armada, et al. [43] develop models to determine optimal combinations of subsidies and guarantees, demonstrating that public support instruments should be calibrated to maximize social welfare while minimizing fiscal exposure. Carbonara, et al. [44] further contribute by proposing a fair risk allocation model that aligns guarantee levels with efficient risk distribution principles, thereby enhancing contract stability and fiscal sustainability. Collectively, these studies situate minimum revenue guarantees within a coherent public finance rationale rather than treating them solely as project level risk mitigation tools.

The second theme highlights the optimization of guaranteed structures and incentive alignment mechanisms. Wang, et al. [45] introduce a Pareto optimal state approach to jointly optimize minimum revenue guarantees and toll revenue caps in highway PPPs, demonstrating how multi objective optimization can balance public welfare and private profitability. Wang and Liu [46] apply principal agent theory to determine optimal excess revenue sharing ratios, addressing information asymmetry and moral hazard concerns that arise when guarantees alter operator incentives. Similarly, Sun and Zhang [12] analyze the integration of minimum revenue guarantees with royalty schemes in a water treatment BOT project, illustrating how calibrated revenue sharing mechanisms can balance public and private stakeholder interests while ensuring long term concession sustainability. These contributions reflect a shift toward contract structures that simultaneously address downside protection and upside sharing within formal optimization frameworks.

The third theme centers on risk adjusted valuation and financial engineering approaches. Ashuri, et al. [47] employ a risk neutral pricing framework to evaluate BOT highway projects with embedded government minimum revenue guarantee options, reinforcing the treatment of guarantees as financial derivatives subject to rigorous pricing techniques. Kokkaew and Chiara [48] extend risk adjusted modeling approaches to privately built transportation projects by incorporating stochastic demand distributions and volatility considerations into guaranteed valuation. Together with the optimal subsidy modeling of Rocha Armada, et al. [43] and the fair risk allocation framework of Carbonara, et al. [44], these studies demonstrate increasing methodological sophistication in quantifying both private benefits and public fiscal exposure under uncertainty.

Moreover, the 2011 to 2015 literature marks a transition from foundational option-based valuation toward integrated fiscal, contractual, and optimization frameworks. Minimum revenue guarantees are conceptualized not only as protective instruments but also as policy tools embedded within welfare maximizing, incentive compatible, and risk adjusted PPP structures. This period establishes the analytical bridge between early financial engineering approaches and the more strategic and sustainability-oriented perspectives that emerge in subsequent years.

Table 4. Thematic Synthesis of MRG Evolution up to 2010 (Source: Authors own work, 2026)

Thematic	Category	Coding
Public Finance and Fiscal Rationale of MRG	Public finance foundations of PPP guarantees	Market failure correction; fiscal illusion mitigation; contingent liability management; risk transfer efficiency; value for money assessment; budget transparency
	Optimal subsidy and guarantee design	Subsidy versus guarantee trade off; welfare maximization; fiscal exposure minimization; demand risk allocation; incentive compatible public support
	Fair risk allocation models	Equitable risk distribution; downside protection calibration; guarantee trigger thresholds; public sector fiscal sustainability; contract stability enhancement
Optimization and Incentive Alignment in Contract Design	Pareto optimal guarantee and revenue cap structures	Multi objective optimization; toll revenue cap calibration; state contingent contracts; social welfare balancing; efficiency frontier analysis
	Principal agent modeling of excess revenue sharing	Information asymmetry mitigation; effort observability; optimal sharing ratio; moral hazard control; incentive compatibility constraints
	MRG and royalty scheme integration in utilities	Balanced stakeholder interests; tariff adjustment mechanisms; royalty calibration; long term concession sustainability; stakeholder payoff equilibrium
Risk Adjusted Valuation and Financial Engineering	Risk neutral pricing of MRG options	Option valuation under uncertainty; risk neutral measure application; traffic demand stochasticity; discounted cash flow integration; financial derivative analogy
	Risk adjusted modeling of transportation guarantees	Revenue distribution estimation; downside risk hedging; volatility adjusted valuation; sensitivity analysis; probabilistic fiscal exposure
	Integrated fiscal and financial evaluation	Public support efficiency measurement; comparative subsidy evaluation; guarantee cost estimation; investment feasibility assessment; contract optimization under uncertainty

C. EVOLUTION OF MINIMUM REVENUE GUARANTEES (2016–2020)

The period from 2016 to 2020 reflects a significant maturation in the evolution of minimum revenue guarantees within public–private partnership infrastructure investment. While earlier decades concentrated primarily on option pricing and fiscal rationalization, the literature during this phase increasingly incorporated strategic interaction, renegotiation dynamics, and sector specific applications into the design of guarantees. Scholars expanded the analytical scope of MRGs to encompass revenue risk sharing mechanisms, game theoretic modeling, sustainable finance considerations, and advanced stochastic simulation techniques. Across the sixteen selected studies, three dominant thematic directions emerge: advanced financial engineering and valuation refinement, strategic interaction and renegotiation frameworks, and sector specific and sustainability-oriented applications of guarantees. Table 5 presents the thematic synthesis for this period.

The first theme highlights advanced financial engineering and valuation refinement, demonstrating the growing sophistication in treating MRGs as structured financial instruments. Research extends real options and stochastic modeling techniques to optimize guarantee sizing, risk allocation, and revenue forecasting. For example, Power, et al. [15] apply strategic option valuation to PPPs, while Buyukyoran and Gundes [49] develop an optimized real options framework for toll road guarantees. Hawas and Cifuentes [17] employ Gaussian copula simulations to capture correlated financial risks, and Zapata Quimbayo, et al. [50] model MRGs using mean-reverting stochastic processes. Complementary studies examine revenue risk sharing [51-53] and incentive-compatible guarantee structures [21], collectively framing MRGs as quantitatively optimized, derivative-like instruments embedded within concession contracts.

The second theme emphasizes strategic interaction and renegotiation mechanisms. Research investigates how MRG design influences private sector behavior, strategic bidding, and dynamic contract governance. Wang, et al. [54] analyze investor responses under government guarantees, whereas Jang, et al. [55] propose a game-theoretic negotiation framework to resolve PPP financial conflicts. Bae, et al. [25] develop renegotiation models that maintain net present value constraints, and Carbonara and Pellegrino [21] address moral hazard through incentive-compatible structures. Additional studies model contingent government interventions as state-contingent financial options in wastewater and transportation projects [13, 56], demonstrating that MRGs function as adaptive policy instruments supporting fiscal sustainability and private sector alignment.

The third theme concerns sector-specific and sustainability-oriented applications, extending MRGs beyond conventional highway concessions. Transportation infrastructure remains central [49, 53, 57], while the water sector emphasizes capacity expansion and long-term fiscal resilience [56, 58]. Utility and urban railway projects illustrate how calibrated MRGs enhance stakeholder outcomes and integrate financial flexibility with sustainable infrastructure development [13, 15, 21, 59].

Collectively, these studies underscore the evolution of MRGs from quantitative financial tools to strategic, sustainability-aligned mechanisms, establishing the foundation for resilience-driven public–private partnership frameworks beyond 2020.

Table 5. Thematic Synthesis of MRG Evolution (2016–2020) (Source: Authors own work, 2026)

Thematic	Category	Coding
Advanced Financial Engineering and Valuation Refinement	Real options and strategic option valuation	Embedded managerial flexibility; staged expansion options; abandonment triggers; contingent finance valuation; option exercise conditions; derivative based pricing logic
	Stochastic and simulation-based modeling	Gaussian copula simulation; mean reverting revenue processes; Monte Carlo valuation; correlated risk factors; volatility calibration; probabilistic fiscal exposure
	Revenue risk sharing optimization	Risk sharing ratio calibration; symmetric upside and downside allocation; government exposure minimization; efficiency frontier analysis; quantitative guarantee sizing; fiscal efficiency benchmarking
Strategic Interaction and Renegotiation Frameworks	Game theoretic modeling of incentives	Investor speculation incentives; strategic bidding behavior; equilibrium analysis; moral hazard mitigation; effort observability constraints; guarantee induced behavior
	Renegotiation and contract adjustment mechanisms	Equivalent NPV constraint; renegotiation triggers; contract stability; financial rebalancing rules; dynamic concession restructuring; post award flexibility
	Government guarantee decision modeling	Expansion stage decision making; wastewater treatment scaling; fiscal sustainability thresholds; contingent support timing; investment inducement analysis; policy response modeling

Thematic	Category	Coding
Sector Specific and Sustainability Oriented Applications	Transportation and toll road PPP applications	Toll revenue volatility; highway traffic demand risk; revenue cap integration; transportation corridor finance; public support calibration; long term concession sustainability
	Water and wastewater utility PPPs	Wastewater expansion risk; tariff adjustment mechanisms; capacity scaling uncertainty; utility demand stability; downside protection in utilities; public health infrastructure finance
	Sustainable and urban rail finance integration	Sustainability aligned finance; contractual rights valuation; exercise condition analysis; long term social value creation; green infrastructure support; balanced stakeholder incentives

D. EVOLUTION OF MINIMUM REVENUE GUARANTEES (2021–2026)

The period from 2021 to 2026 represents a phase of strategic consolidation and sustainability integration in the evolution of minimum revenue guarantees within public–private partnership infrastructure investment. Building on prior advances in real options valuation, optimization, and renegotiation theory, recent scholarship increasingly positions minimum revenue guarantees as dynamic, performance-sensitive, and sustainability-aligned policy instruments. The fifteen selected studies published during this period reflect three dominant thematic directions: strategic and game-theoretic contract optimization, adaptive and performance-linked guarantee mechanisms, and sustainability-oriented and sector-specific financial structuring. Table 5 presents a thematic synthesis derived from these studies.

The first theme emphasizes strategic and game-theoretic contract optimization, highlighting MRGs as embedded strategic instruments within multi-actor PPP environments. Research demonstrates that governments and private investors co-determine optimal risk sharing under uncertainty through approaches such as strategic options games [16] and swing option revenue allocation models [60]. Further studies integrate concession period determination with MRG calibration [24, 61] and develop robust contract designs under deep demand uncertainty [29]. Mechanisms such as barrier real options [20] and comparative analyses of public support instruments [62] indicate that MRGs have evolved toward equilibrium-based, strategically optimized, and behaviorally informed contract structures.

The second theme concerns adaptive and performance-linked MRG mechanisms that incorporate operational realism and dynamic value creation. Examples include dynamic profit distribution integrating option logic [23], capacity-constrained guarantee designs [22], and structured early termination clauses [63], which collectively demonstrate the integration of operational thresholds and flexible contract adjustment. Decision frameworks for efficient risk mitigation in highway build–operate–transfer projects [26] further emphasize the role of adaptive and calibrated support mechanisms in balancing fiscal prudence with investor incentives. Together, these studies suggest that contemporary MRG frameworks increasingly focus on lifecycle value creation and operationally informed contract structures.

The third theme highlights the expansion of MRG applications into sustainability-oriented and emerging infrastructure sectors. Real options analysis has been applied to enhance the viability of renewable energy projects [27], while demand guarantees stabilize investment in island off-grid energy systems [6]. Financial screening tools for electric vehicle charging infrastructure [28] and revenue risk sharing in post-disaster housing reconstruction [18] exemplify resilience-oriented allocation models [26, 60].

Overall, MRGs are increasingly conceptualized as strategic, adaptive, and sustainability-aligned instruments that mobilize private investment in resilient, low-carbon, and innovative infrastructure systems

Table 6. Thematic Synthesis of MRG Evolution (2021–2026) (Source: Authors own work, 2026)

Thematic	Category	Coding
Strategic and Game-Theoretic Contract Optimization	Strategic options and multi-stage game modeling	Strategic options games; equilibrium investment timing; state-contingent guarantees; intertemporal decision rules; risk-sharing equilibrium calibration
	Concession parameter joint optimization	Concession period calibration; minimum revenue guarantee threshold optimization; sustainable contract design; joint parameter optimization; lifecycle equilibrium modeling
	Moral hazard mitigation and behavioral control	Barrier option safeguards; speculation control; incentive compatibility constraints; opportunistic behavior prevention; performance-contingent triggers

Thematic	Category	Coding
Adaptive and Performance-Linked Guarantee Mechanisms	Dynamic profit sharing and value creation	Dynamic profit distribution; option-embedded revenue sharing; adaptive payoff structures; lifecycle value maximization; flexible upside sharing
	Capacity constraints and operational realism	Capacity-sensitive guarantees; infrastructure scaling limits; congestion effects; operational threshold calibration; fiscal sustainability under constraints
	Early termination and contract adjustment	Termination compensation logic; downside risk containment; renegotiation triggers; fiscal loss limitation; contract stability preservation
Sustainability-Oriented and Sector-Specific Financial Structuring	Renewable energy and climate-aligned guarantees	Photovoltaic real options; flexible supportive policy; renewable demand uncertainty; climate-aligned fiscal support; green investment inducement
	Electric mobility and emerging infrastructure	Electric vehicle charging public–private partnership screening; demand uncertainty modeling; alternative public–private partnership structures; viability benchmarking; scalable green infrastructure finance
	Post-disaster and resilience finance	Reconstruction revenue risk sharing; swing option allocation; disaster recovery incentives; resilience investment support; uncertainty-adaptive contracts

E. CONCEPTUAL FRAMEWORK FOR MRGs IN PPP INFRASTRUCTURE INVESTMENT

The preceding analysis underscores the progressive evolution of minimum revenue guarantees (MRGs) in public–private partnership infrastructure projects, from early risk mitigation instruments to sophisticated strategic, adaptive, and sustainability-aligned mechanisms. To synthesize these historical and contemporary insights, a conceptual framework is proposed to guide the practical implementation of MRGs across diverse infrastructure sectors. This framework integrates three core dimensions: strategic and game-theoretic contract optimization, adaptive and performance-linked guarantee mechanisms, and sustainability-oriented, sector-specific financial structuring. By linking these dimensions, the framework provides a structured approach for policymakers and practitioners to design MRGs that balance fiscal prudence, investor incentives, and long-term infrastructure resilience. The framework is illustrated in Figure 1.

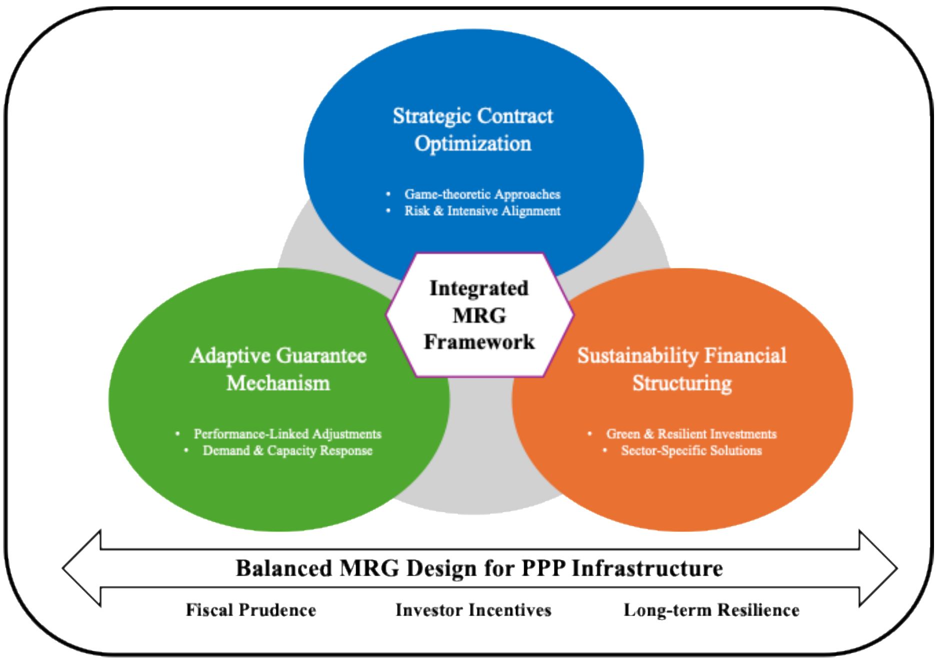

Figure 1. Conceptual Framework f (Source: Authors own work, 2026)

The framework conceptualizes MRGs as dynamic, multidimensional instruments embedded within PPP contracts. Strategic contract design ensures that MRGs are aligned with equilibrium-based decision-making and behavioral incentives. Adaptive mechanisms account for operational constraints and lifecycle value considerations, allowing guarantees to respond to demand fluctuations and capacity limitations. Sustainability-oriented, sector-specific applications extend the relevance of MRGs to green and resilient infrastructure, ensuring that financial instruments support long-term social, environmental, and economic objectives. By integrating these elements, the framework provides a comprehensive roadmap for designing MRGs that are analytically rigorous, strategically informed, and practically implementable. This framework bridges the historical evolution of MRGs with contemporary innovations, offering a practical reference for effective risk management and investment mobilization in complex PPP infrastructure projects.

CONCLUSIONS

This study synthesizes the evolution of MRGs in PPP infrastructure investment and demonstrates their progression from basic risk mitigation instruments to strategically optimized, adaptive, and sustainability oriented financial mechanisms. The review process screened 415 records from Scopus and Web of Science and identified 44 eligible studies for qualitative analysis. The final sample consisted of 5 studies published up to 2010, 8 studies during 2011 to 2015, 16 studies during 2016 to 2020, and 15 studies during 2021 to 2026, reflecting a substantial increase in scholarly attention to MRG design and application over time.

The findings reveal four evolutionary phases. The first phase emphasized option-based valuation and stochastic modeling of guarantees. The second phase focused on fiscal rationalization, contract optimization, and incentive alignment. The third phase expanded toward strategic interaction, renegotiation frameworks, and sector specific applications. The fourth phase advanced the integration of strategic optimization, adaptive contract mechanisms, and sustainability-oriented infrastructure finance. Across these phases, MRGs increasingly incorporated real options analysis, game theoretic modeling, dynamic profit-sharing arrangements, and performance sensitive contractual structures that balance government fiscal exposure with private investment incentives.

This study contributes to theory and practice through the development of a comprehensive conceptual framework that integrates three core dimensions: strategic and game theoretic contract optimization, adaptive and performance linked guarantee mechanisms, and sustainability-oriented sector specific financial structuring. The framework provides policymakers and practitioners with a structured approach for designing MRGs that enhance investment feasibility, mitigate revenue risk, support operational flexibility, and align infrastructure finance with broader economic, social, and environmental objectives.

The novelty of this study lies in its synthesis of multi decade developments across 44 peer reviewed studies and its integration of contemporary adaptive and sustainability-oriented mechanisms into a unified MRG framework. Despite these contributions, the study is limited by its reliance on qualitative synthesis of English language peer reviewed literature. Future research should employ empirical and quantitative approaches across diverse infrastructure sectors, evaluate MRG effectiveness in emerging markets, and investigate the role of digital finance, artificial intelligence, and real time performance monitoring in supporting adaptive guarantee mechanisms. Such efforts would further strengthen the design and implementation of MRGs in increasingly dynamic and sustainability driven infrastructure environments.

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