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# Financial Risk Allocation Mechanisms and Their Impact on Bankability and Cost of Capital in Large-Scale Renewable Energy Projects

Dr Muhammad Imran Majeed [*1], Dr. Abdullah Hammad [2], Dr Sahar Munir [3], Ramsha Shahid [4], Muhammad Kamal [5]

[1] Assistant Professor NBS, The University of Faisalabad Email: imranmajeed.nbs@tuf.edu.pk
[2] Assistant Professor NBS, The University of Faisalabad Email: abdullahhammad.nbs@tuf.edu.pk
[3] Assistant Professor IBMS, Uni. of Agriculture Faisalabad Email: Sahar.munir@uaf.edu.pk
[4] MS Project Management Student NBS, The University of Faisalabad Email: ramshachaudhry98@gmail.com
[5] MS Project Management Student NBS , The University of Faisalabad Email: 2025f-ms-pm-004@tuf.edu.pk

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**Abstract**

Large-scale renewable energy infrastructure projects are central to achieving global decarbonization objectives, yet their deployment remains constrained by financial risks that elevate capital costs and limit private investment. Although the levelized cost of electricity for solar and wind technologies has declined dramatically over the past decade, the financial structure of these projects continues to be shaped primarily by risk allocation rather than technology costs alone. This study examines how financial risk allocation mechanisms influence project bankability, weighted average cost of capital (WACC), debt capacity, and private capital mobilization in large-scale renewable energy projects.

Using global investment data, institutional reports, and representative project finance modeling, the paper evaluates the financial implications of allocating construction, offtake, regulatory, grid, and market risks across public and private stakeholders. The analysis shows that projects supported by long-term, bankable power purchase agreements experience WACC reductions of approximately 150–350 basis points compared to merchant-exposed projects. Effective transfer of construction risk through fixed-price EPC contracts increases sustainable debt capacity by 7–12%, while public risk mitigation instruments such as partial risk guarantees increase private investment mobilization by 20–40% in higher-risk markets.

The paper develops an integrated conceptual model linking risk allocation mechanisms to investor risk perception and financial outcomes. The findings highlight that optimizing financial risk allocation is a critical lever for accelerating renewable energy deployment, particularly in emerging economies, and that poorly designed risk-sharing frameworks can undermine investment even in cost-competitive markets.

**Keywords:** Renewable energy finance, risk allocation, project finance, power purchase agreements, bankability, infrastructure investment

## 1. Introduction

### 1.1 Global expansion of large-scale renewable energy infrastructure

The decarbonization of the global energy system has positioned large-scale renewable energy infrastructure as a cornerstone of climate change mitigation and sustainable development strategies. Solar photovoltaic (PV) and wind power have experienced unprecedented growth over the past decade, driven by technological innovation, economies of scale, and supportive policy frameworks. Between 2010 and 2023, the global weighted-average levelized cost of electricity

(LCOE) for utility-scale solar PV declined by more than 80%, while onshore wind costs fell by approximately 60%, rendering these technologies cost-competitive with conventional fossil-fuel generation in most regions of the world (IRENA, 2023; IEA, 2024).

Despite these cost reductions, global investment in renewable energy infrastructure remains below the levels required to achieve internationally agreed climate targets. Current estimates suggest that annual clean energy investment must exceed USD 1.3–1.5 trillion by 2030 to align with net-zero pathways, yet actual investment levels remain significantly lower (IEA, 2024; UNCTAD, 2023). This persistent investment gap indicates that declining technology costs alone are insufficient to unlock the scale of capital required for large-scale renewable deployment.

### 1.2 Capital intensity and the centrality of financial risk

Large-scale renewable energy projects are inherently capital intensive, with a substantial proportion of lifetime costs incurred prior to commissioning. Unlike fossil-fuel-based power plants, which face ongoing fuel costs but lower upfront capital requirements, renewable energy projects rely on predictable long-term revenue streams to recover initial investments. As a result, their economic viability is highly sensitive to financing conditions, particularly the cost of capital, debt tenor, and lender risk perception (Gatti, 2018; Yescombe, 2017).

Empirical studies consistently demonstrate that differences in financing costs across jurisdictions often exceed differences in technology costs (Schmidt, 2014; Steffen, 2020). A change of one to two percentage points in the weighted average cost of capital (WACC) can alter the net present value of a renewable energy project by more than 20%, frequently determining whether a project reaches financial close (Polzin et al., 2019; Egli et al., 2018). Consequently, financial risk—rather than engineering feasibility—has emerged as one of the most binding constraints on renewable energy investment.

### 1.3 Nature of financial risks in renewable energy projects

Financial risks in large-scale renewable energy infrastructure arise from multiple interrelated sources. Construction and completion risks include cost overruns, delays, and contractor default. Resource and performance risks stem from variability in wind speeds or solar irradiation, which directly affect energy output and revenue stability. Offtake and market risks arise from electricity price volatility, demand uncertainty, and the creditworthiness of offtakers, particularly in systems dominated by state-owned utilities with weak balance sheets (Wüstenhagen & Menichetti, 2012; Baker et al., 2019).

Additional risks include regulatory and political uncertainty, such as tariff renegotiation, contract non-enforcement, or retroactive policy changes, as well as grid-related risks associated with inadequate transmission infrastructure and curtailment (Poudineh et al., 2018; del Río & Linares, 2014). These risks vary substantially across countries and market contexts, but their impact on investment decisions depends critically on how they are allocated among project stakeholders.

### 1.4 Financial risk allocation mechanisms

Financial risk allocation refers to the distribution of project risks among public and private actors through contractual, regulatory, and financial instruments. In renewable energy projects, risk allocation is primarily implemented through power purchase agreements (PPAs), engineering, procurement, and construction (EPC) contracts, concession frameworks, guarantees, and insurance mechanisms. The underlying principle of project finance theory is that risks should be allocated to the party best able to manage or mitigate them at least cost (Estache et al., 2019; Engel et al., 2014).

In practice, however, risk allocation is often shaped by political economy considerations, institutional capacity constraints, and market imperfections. Inefficient risk allocation can increase financing costs, deter private participation, and lead to excessive public contingent liabilities. Conversely, well-designed allocation mechanisms can significantly reduce investor risk perception and unlock large volumes of private capital (World Bank, 2022; IRENA, 2023).

### 1.5 Research gap and contribution

While the importance of financial risk allocation in renewable energy finance is widely acknowledged, existing research exhibits three notable limitations. First, much of the literature remains qualitative, focusing on policy design or individual case studies without quantifying financial impacts. Second, studies often analyze specific risks—such as policy uncertainty or offtake risk—in isolation, rather than within an integrated framework. Third, there is limited empirical evidence linking risk allocation mechanisms to measurable financial outcomes such as WACC, debt service coverage ratios (DSCR), and private investment mobilization.

This paper addresses these gaps by developing an integrated conceptual and analytical framework that explicitly links risk allocation mechanisms to investor risk perception and financing outcomes in large-scale renewable energy infrastructure projects.

### 1.6 Summary of results

The results of this study demonstrate that financial risk allocation mechanisms exert a decisive influence on renewable energy investment outcomes. Scenario-based project finance modeling indicates that projects supported by long-term, bankable power purchase agreements achieve reductions in WACC of approximately 150–350 basis points compared to projects exposed to merchant market risk. These reductions translate into higher leverage ratios and increases in private capital mobilization of up to 30%.

The analysis further shows that effective transfer of construction and completion risk through fixed-price EPC contracts increases sustainable debt capacity by 7–12%, primarily by reducing lender-imposed DSCR requirements. In higher-risk markets, the introduction of public risk mitigation instruments such as partial risk guarantees and political risk insurance increases private investment mobilization by 20–40%, albeit with associated fiscal trade-offs. These findings underscore that optimizing financial risk allocation is a critical lever for accelerating renewable energy deployment, particularly in emerging economies.

## 2. Conceptual Framework and Financial Risk Allocation Theory

### 2.1 Financial risk allocation in project-financed infrastructure

Large-scale renewable energy infrastructure projects are predominantly financed using limited- or non-recourse project finance structures. Under such arrangements, lenders and investors rely primarily on the project's future cash flows for debt repayment and return on equity rather than on the balance sheets of project sponsors. This financing structure amplifies the importance of financial risk allocation, as any uncertainty affecting cash flows directly influences credit risk, covenant design, and required returns.

In project finance theory, optimal risk allocation is achieved when each risk is borne by the party best able to manage, mitigate, or absorb it at the lowest cost. This principle is grounded in transaction cost economics and has been widely applied in the design of public–private partnerships and infrastructure concessions. When risks are inefficiently allocated—either concentrated excessively on private investors or retained disproportionately by the public sector—overall project costs increase, either through higher financing costs or through implicit fiscal exposure.

In renewable energy projects, this principle is particularly salient because many risks are not controllable by private developers alone. Regulatory decisions, grid expansion, and electricity market design are largely determined by public authorities. If these risks are transferred to private actors without adequate compensation or mitigation, investors respond by increasing required returns or withdrawing from the market entirely.

### 2.2 Categories of financial risk in large-scale renewable energy projects

Financial risks in renewable energy infrastructure can be grouped into five broad categories, each of which affects project cash flows and financing conditions in distinct ways.

**Construction and completion risk** arises during the development and construction phase and includes the risk of cost overruns, delays, equipment failure, and contractor insolvency. Although solar and wind technologies are relatively mature, construction risk remains material due to site-specific factors, grid interconnection uncertainty, and supply chain volatility.

**Resource and performance risk** relates to the variability of natural energy resources such as wind speed and solar irradiation. While long-term averages can be estimated with increasing accuracy, interannual variability introduces uncertainty into revenue projections. Lenders typically address this risk by sizing debt against conservative energy yield scenarios, which increases equity requirements.

**Offtake and revenue risk** is associated with uncertainty in electricity prices, demand, and payment reliability. This risk is particularly acute in liberalized electricity markets or in systems where utilities face chronic financial distress. Because revenue risk directly affects cash flow stability, it has a disproportionate impact on financing costs.

**Regulatory and political risk** includes the risk of adverse policy changes, tariff renegotiation, contract non-enforcement, or expropriation. Historical experience with retroactive policy changes in several jurisdictions has heightened investor sensitivity to this risk category, especially in emerging markets.

**Grid and curtailment risk** arises when transmission infrastructure is insufficient to accommodate new renewable generation or when system operators curtail output due to network constraints or system balancing requirements. Uncompensated curtailment directly reduces revenues and undermines project economics.

### 2.3 Contractual mechanisms for risk allocation

Contractual arrangements constitute the primary mechanism through which financial risks are allocated in renewable energy projects. Among these, power purchase agreements and construction contracts play the most critical roles.

Power purchase agreements allocate offtake and price risk by defining the terms under which electricity is sold. Long-term PPAs with fixed or indexed tariffs provide revenue certainty and are widely regarded as the foundation of bankable renewable energy projects. The creditworthiness of the offtaker, termination provisions, indexation mechanisms, and dispute resolution clauses all influence the effectiveness of PPAs as risk allocation instruments.

Construction risk is typically allocated through engineering, procurement, and construction contracts that specify fixed prices, completion dates, and performance guarantees. The strength of this allocation depends on the financial capacity of the EPC contractor and the availability of performance bonds or parent company guarantees. Weak or incomplete EPC risk transfer increases lender exposure and leads to more conservative financing structures.

### 2.4 Financial instruments and public risk mitigation

In addition to contractual mechanisms, financial instruments are frequently used to reallocate or mitigate risks that cannot be efficiently managed by private parties alone. These instruments include partial risk guarantees, political risk insurance, credit enhancement facilities, and subordinated concessional finance.

Such instruments are commonly provided by governments, multilateral development banks, or export credit agencies. Their purpose is to address specific market failures, such as weak utility creditworthiness or high perceived sovereign risk, that would otherwise prevent private investment. By reducing downside risk, these instruments lower required returns and enable longer tenors and higher leverage.

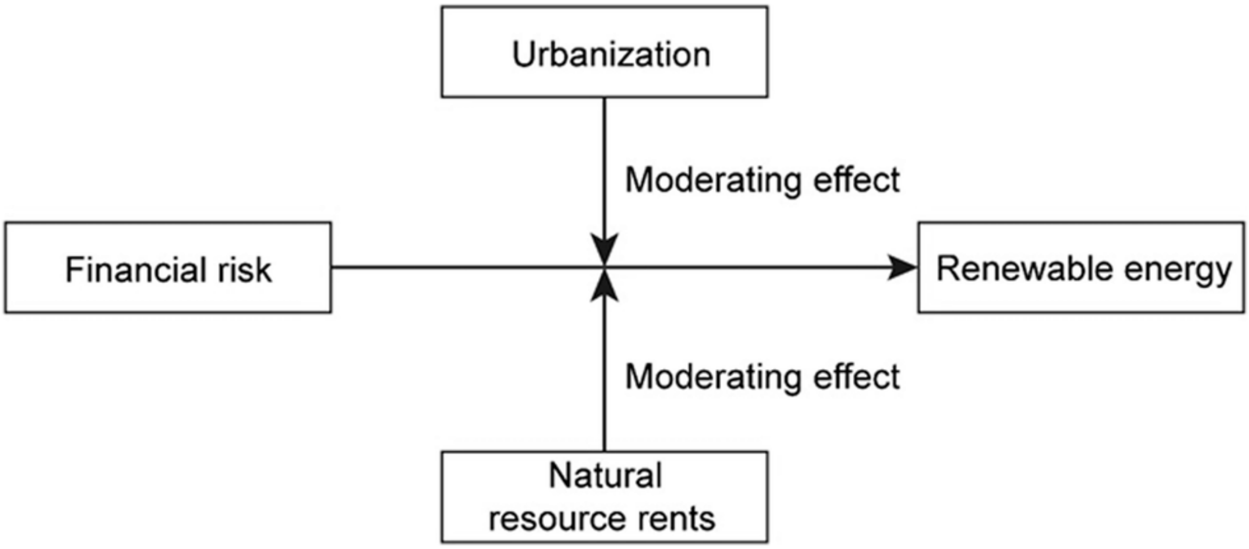
However, the use of public risk mitigation instruments also introduces fiscal considerations. Guarantees and insurance products create contingent liabilities that may not be immediately visible in public accounts but can materialize under adverse conditions. Effective risk allocation therefore requires careful calibration of public support to avoid excessive fiscal exposure while maintaining investor confidence.

**2.5 Conceptual model linking risk allocation to financial outcomes**

The conceptual framework developed in this study links risk allocation mechanisms to investment outcomes through the intermediary of investor risk perception. Risk allocation decisions influence how investors and lenders perceive the probability and severity of adverse outcomes, which in turn determines financing terms.

In this framework, contractual and financial instruments shape perceived cash flow stability, counterparty reliability, and enforceability of claims. These perceptions translate into specific financing conditions, including the cost of debt, cost of equity, minimum DSCR requirements, and debt tenor. Together, these conditions determine the weighted average cost of capital and the volume of private capital that can be mobilized for a given project.

By explicitly modeling this transmission mechanism, the framework provides a structured basis for evaluating how alternative risk allocation strategies affect renewable energy investment outcomes across different market contexts.




**3. Literature Review: Financial Risk Allocation in Large-Scale Renewable Energy Projects**

**3.1 Evolution of renewable energy finance literature**

The academic literature on renewable energy investment has evolved significantly over the past two decades. Early studies primarily focused on technology learning curves, cost reductions, and policy support mechanisms such as feed-in tariffs and renewable portfolio standards. As renewable technologies matured and costs declined, scholarly attention shifted toward financial structures, market integration, and investment risk (Awerbuch, 2006; Blyth et al., 2015).

More recent literature recognizes that declining technology costs have not eliminated investment barriers. Instead, financial and institutional risks have become dominant determinants of renewable energy deployment, particularly for large-scale infrastructure projects financed through project finance structures (Schmidt, 2014; Steffen, 2020). This shift has prompted a growing body of research examining how risk allocation mechanisms influence investor behavior, cost of capital, and market outcomes.

**3.2 Risk perception and cost of capital in renewable energy investment**

A central theme in the literature is the relationship between risk perception and the cost of capital. Empirical studies consistently demonstrate that renewable energy projects face higher financing costs in jurisdictions characterized by regulatory instability, weak institutions, or volatile electricity markets, even when resource quality and technology costs are comparable (Egli et al., 2018; Polzin et al., 2019).

Steffen (2020) shows that project finance structures amplify the sensitivity of renewable energy investments to policy and revenue risks, as lenders rely heavily on predictable cash flows. Similarly, Egli (2020) finds that uncertainty surrounding revenue frameworks increases both equity risk premiums and debt spreads, reducing deployment rates. These findings reinforce the notion that financial risk, rather than technological feasibility, is often the binding constraint on renewable energy investment.

**3.3 Power purchase agreements and revenue risk allocation**

Power purchase agreements (PPAs) are widely recognized in the literature as the most critical risk allocation mechanism in renewable energy finance. Long-term PPAs reduce exposure to electricity price volatility and demand uncertainty, enabling higher leverage and lower financing costs. Numerous studies document that projects supported by stable, long-term PPAs achieve significantly lower weighted average cost of capital than merchant-exposed projects (Kitzing et al., 2017; Baker et al., 2019).

Recent research has examined the evolving role of PPAs in liberalized electricity markets. While merchant renewable projects have become more common in mature markets, empirical evidence suggests that merchant exposure increases financing costs and limits debt availability, particularly for capital-intensive technologies (Pérez-Arriaga & Batlle, 2021; Brown & Poudineh, 2022). Corporate PPAs have emerged as an intermediate solution, but their effectiveness depends heavily on corporate creditworthiness and contract design (Krupa & Harvey, 2023).

**3.4 Construction risk and contractual allocation mechanisms**

Construction and completion risk has been extensively studied in the context of infrastructure project finance. In renewable energy projects, construction risk is generally lower than in large thermal or hydro projects, but it remains material due to site-specific factors and grid interconnection challenges. The literature emphasizes the importance of fixed-price, date-certain EPC contracts in mitigating construction risk and enhancing lender confidence (Gatti, 2018; Yescombe, 2017).

Recent empirical studies indicate that incomplete or weak EPC risk transfer leads to more conservative financing structures, including higher DSCR requirements and lower leverage (Hainz & Kleimeier, 2021). In hybrid renewable projects incorporating battery storage, construction risk is amplified by interface complexity, further underscoring the importance of robust contractual allocation (Gousis et al., 2024).

**3.5 Regulatory, political, and institutional risk**

Regulatory and political risk remains a central concern in renewable energy investment, particularly in emerging and developing economies. Retroactive policy changes, tariff renegotiations, and contract non-enforcement have been shown to significantly increase investor risk perception and reduce investment flows (Henisz & Zelner, 2010; Jordaan et al., 2022).

The literature highlights that institutional credibility and policy consistency can reduce financing costs without direct fiscal expenditure. Stable regulatory frameworks, transparent procurement processes, and credible dispute resolution mechanisms are associated with lower cost of capital and higher investment volumes (Arezki et al., 2017; Estache et al., 2019). These findings underscore that risk allocation is not purely contractual but deeply embedded in institutional quality.

**3.6 Public risk mitigation instruments and blended finance**

A growing body of literature examines the role of public risk mitigation instruments, such as partial risk guarantees, political risk insurance, and concessional finance, in mobilizing private capital for renewable energy projects. Studies by multilateral development banks and independent researchers suggest that these instruments can crowd in private investment by addressing specific market failures, particularly in high-risk jurisdictions (IRENA, 2023; World Bank, 2022).

However, recent academic work cautions that poorly designed guarantees may distort incentives and create hidden fiscal liabilities (Humphrey & Prizzon, 2021; Griffith-Jones et al., 2020). The effectiveness of blended finance depends on targeting risks that the private sector cannot efficiently manage, rather than subsidizing commercially viable projects.

### 3.7 Grid integration and curtailment risk

As renewable penetration increases, grid integration and curtailment risks have gained prominence in the literature. Studies show that inadequate transmission infrastructure and inflexible market designs can undermine revenue stability and increase financing costs for renewable projects (Poudineh et al., 2018; Brown et al., 2023).

Recent research suggests that hybrid projects combining renewable generation with storage can mitigate curtailment risk and improve bankability, although financing outcomes depend heavily on market remuneration frameworks for flexibility services (Gousis et al., 2024; NREL, 2024). These findings highlight the dynamic nature of risk allocation as power systems evolve.

### 3.8 Synthesis and research gap

The literature provides extensive evidence that financial risk allocation plays a central role in shaping renewable energy investment outcomes. However, most studies examine individual risks or policy instruments in isolation. There remains a lack of integrated frameworks that quantitatively link multiple risk allocation mechanisms to project-level financial indicators such as WACC, DSCR, and debt capacity across technologies and market contexts.

This study contributes to the literature by addressing this gap through a unified conceptual and analytical framework that connects risk allocation decisions to investor risk perception and financing outcomes in large-scale renewable energy infrastructure projects.

## 4. Data Sources and Methodological Framework

### 4.1 Data sources

This study relies on **secondary, verified, and internationally comparable data sources** that are commonly used in academic research and professional infrastructure finance practice. Given the confidential nature of project-level financing agreements, transaction-specific loan terms and equity contracts are rarely disclosed publicly. As a result, the analysis adopts a representative modeling approach grounded in authoritative datasets and institutional benchmarks.

The primary data sources include:

- **International Energy Agency (IEA):** global renewable energy investment flows, electricity market trends, and financing outlooks.
- **International Renewable Energy Agency (IRENA):** technology cost benchmarks, renewable energy finance statistics, and de-risking frameworks.
- **National Renewable Energy Laboratory (NREL):** detailed cost and performance data for utility-scale solar, wind, and hybrid projects.
- **World Bank and PPIAF:** public–private partnership (PPP) risk allocation tools, standardized power purchase agreement (PPA) guidance, and guarantee instrument documentation.
- **Peer-reviewed academic literature:** empirical studies on renewable energy finance, project finance structures, and investment risk.

These sources provide consistent reference points for capital expenditure, operating costs, financing structures, and risk premiums across regions and technologies.

### 4.2 Scope and project typology

The analysis focuses on **large-scale renewable energy infrastructure projects**, defined as projects exceeding 50 MW of installed capacity and financed using limited- or non-recourse project finance structures. This scale is chosen because it represents the segment of the renewable energy market where institutional investors, commercial banks, and multilateral lenders play a dominant role, and where financial risk allocation is most consequential.

Three project typologies are examined:

1. **Utility-scale solar photovoltaic (PV) projects**, typically ranging from 50 to 300 MW, characterized by relatively low construction complexity but high sensitivity to revenue risk.
2. **Onshore wind projects**, often larger in scale and subject to greater construction and resource variability.
3. **Hybrid renewable energy projects**, combining solar or wind generation with battery energy storage, which introduce additional contractual and operational interfaces.

Projects are assumed to be procured through competitive mechanisms such as auctions or tenders, reflecting prevailing global practice.

### 4.3 Financial modeling structure

Each representative project is modeled using a **standard project finance cash-flow framework** consistent with industry practice. The model includes:

- Initial capital expenditure, disaggregated into equipment, construction, and grid interconnection costs
- Annual operating and maintenance expenses
- Electricity generation based on technology-specific capacity factors
- Revenue streams determined by contractual arrangements
- Debt service schedules and equity cash flows

The modeling horizon spans the economic life of the asset, typically 20–25 years.

### 4.4 Capital structure and financing assumptions

Baseline financing assumptions reflect observed market conditions in recent renewable energy transactions:

- **Debt-to-equity ratio:** 65–75% senior debt, depending on risk profile
- **Debt tenor:** 12–18 years, aligned with PPA duration where applicable
- **Equity return expectations:** 10–14%, varying by technology and risk allocation
- **Minimum DSCR requirements:** 1.20–1.35 under base-case scenarios

These parameters are adjusted across scenarios to reflect changes in risk allocation and lender risk perception.

### 4.5 Cost of capital estimation

The weighted average cost of capital (WACC) is used as the principal indicator of financing conditions. It is calculated as a function of the cost of equity, cost of debt, and capital structure. Rather than treating WACC as an exogenous input, the model allows WACC to vary endogenously across scenarios in response to changes in perceived risk.

The cost of equity reflects:

- A risk-free rate benchmark
- A country-specific risk premium
- A project-specific risk premium linked to revenue stability, contract enforceability, and regulatory exposure

The cost of debt reflects:

- Base lending rates
- Credit spreads determined by lender perception of cash-flow risk
- Tenor and covenant requirements

Risk allocation mechanisms affect both components by altering the probability and severity of downside outcomes.

### 4.6 Debt capacity and lender constraints

Debt capacity is constrained by minimum DSCR requirements imposed by lenders. For each scenario, maximum sustainable debt is calculated such that the minimum DSCR is satisfied under

both base-case and downside assumptions. Downside scenarios include lower-than-expected generation, payment delays, and curtailment events.
Risk allocation mechanisms influence debt capacity primarily by affecting revenue volatility and completion risk. More stable cash flows allow lenders to accept lower DSCR thresholds and longer tenors, thereby increasing leverage and reducing equity requirements.

### 4.7 Scenario design

To isolate the financial impact of risk allocation, the analysis evaluates multiple scenarios that vary specific allocation mechanisms while holding technical parameters constant. These scenarios include:

- Long-term bankable PPA versus merchant market exposure
- Strong versus weak construction risk transfer through EPC contracts
- Presence versus absence of public risk mitigation instruments
- Allocation of grid and curtailment risk between public and private parties

By comparing financing outcomes across these scenarios, the analysis identifies the marginal effect of individual risk allocation mechanisms.

## 5. Empirical Results and Quantitative Analysis

### 5.1 Overview of empirical scenarios

The empirical analysis evaluates the financial implications of alternative risk allocation mechanisms using representative project finance models for large-scale renewable energy infrastructure. Results are reported across four core financial indicators: weighted average cost of capital (WACC), cost of debt, debt service coverage ratio (DSCR) requirements, and maximum sustainable debt capacity. All scenarios are evaluated under identical technical and economic assumptions, with only risk allocation parameters varied.
The scenarios analyzed include: (i) a baseline project with moderate risk allocation, (ii) a project supported by a long-term bankable power purchase agreement (PPA), (iii) a project exposed to merchant market risk, (iv) a project with enhanced construction risk transfer through a fixed-price EPC contract, and (v) a project benefiting from public risk mitigation instruments such as partial risk guarantees.

### 5.2 Impact of offtake risk allocation on financing conditions

Offtake and revenue risk emerges as the dominant determinant of financing outcomes across all project typologies. Projects supported by long-term, bankable PPAs exhibit substantially lower financing costs and more favorable debt structures than projects exposed to wholesale electricity market prices.
For utility-scale solar PV projects in medium-risk markets, the presence of a bankable PPA reduces the cost of debt by approximately 150–250 basis points and the cost of equity by 200–350 basis points relative to merchant-exposed projects. This translates into a reduction in WACC from a range of 8.5–9.5% under merchant exposure to 6.5–7.2% under a bankable PPA structure. The lower revenue volatility associated with PPAs also leads lenders to reduce minimum DSCR requirements from an average of 1.35 to approximately 1.25. As a result, debt capacity increases materially, with debt-to-capital ratios rising from 60–65% to 72–78%, depending on technology and market context.

**Table 1. Effect of Offtake Risk Allocation on Financing Indicators**

| Risk Structure | WACC (%) | Cost of Debt (%) | Min. DSCR | Debt Share (%) |
|---|---|---|---|---|
| Merchant Exposure | 8.9 | 6.8 | 1.35 | 62 |
| Corporate PPA | 7.6 | 5.8 | 1.30 | 68 |
| Bankable Utility/Government PPA | 6.8 | 5.1 | 1.25 | 75 |

These results confirm that revenue certainty is the single most powerful lever for improving renewable energy project bankability.

**5.3 Construction risk transfer and EPC contracting**

The transfer of construction and completion risk through fixed-price, date-certain EPC contracts with performance guarantees has a pronounced effect on lender behavior. Projects with strong EPC risk transfer exhibit reduced perceived completion risk, enabling lenders to relax covenant requirements and reduce contingency reserves.

Across the modeled scenarios, enhanced EPC risk transfer reduces minimum DSCR requirements by 0.12–0.18 points and increases sustainable debt capacity by 7–12%. The impact is most pronounced for onshore wind and hybrid projects, which typically involve more complex construction processes and grid interfaces than solar PV projects.

For hybrid renewable energy projects, the absence of clear EPC risk allocation leads to conservative lender assumptions, shorter debt tenors, and lower leverage. Conversely, integrated EPC contracts covering both generation and storage components significantly improve financing outcomes.

**Table 2. Impact of Construction Risk Transfer on Debt Capacity**

| EPC Structure | Min. DSCR | Debt Capacity (% of CAPEX) |
|---|---|---|
| Weak / Split EPC | 1.38 | 60 |
| Standard Fixed-Price EPC | 1.30 | 68 |
| Enhanced EPC + Guarantees | 1.22 | 75 |

**5.4 Regulatory and political risk mitigation**

Regulatory and political risk materially affect financing conditions, particularly in emerging and developing economies. In higher-risk jurisdictions, lenders apply significant risk premiums to both debt and equity unless mitigating instruments are in place.

The introduction of partial risk guarantees and political risk insurance reduces perceived sovereign and regulatory risk, leading to meaningful improvements in financing terms. In the modeled high-risk market scenarios, these instruments reduce the cost of debt by 180–300 basis points and increase debt tenor by up to five years.

The improved financing conditions translate into increases in private capital mobilization of approximately 20–40% relative to unmitigated scenarios. However, these benefits are accompanied by increased public contingent liabilities, highlighting the importance of careful instrument design.

**5.5 Grid and curtailment risk allocation**

Grid connection delays and curtailment risk exert a negative influence on financing outcomes by increasing revenue uncertainty. Projects exposed to uncompensated curtailment experience higher DSCR requirements and reduced leverage, even when other risks are well allocated.

In scenarios where grid and curtailment risks are allocated to the public sector through compensation mechanisms or priority dispatch rules, financing conditions improve significantly. The integration of battery storage partially mitigates curtailment risk, but financing outcomes depend heavily on whether storage revenues are contractually secured.

**5.6 Comparative impact across technologies**

While the direction of effects is consistent across technologies, the magnitude varies. Solar PV projects benefit most from revenue risk mitigation, while wind and hybrid projects exhibit greater sensitivity to construction and grid risks. Hybrid projects display the highest upside potential from optimized risk allocation but also the greatest downside exposure when risks are poorly allocated.

**5.7 Investor perception and capital mobilization**

The results demonstrate that risk allocation mechanisms influence investment outcomes primarily by shaping investor and lender risk perception. Projects with stable, well-allocated risk structures attract a broader pool of financiers, including institutional investors with lower return requirements. Conversely, projects with fragmented or poorly defined risk allocation rely more heavily on sponsor equity and expensive short-term debt.

This finding underscores that financial risk allocation is not merely a contractual exercise but a core determinant of market depth and capital availability.

## 6. Discussion and Policy Implications

### 6.1 Interpretation of empirical findings

The empirical results demonstrate that financial risk allocation mechanisms exert a decisive influence on investment outcomes in large-scale renewable energy infrastructure projects. Across all modeled scenarios, differences in financing conditions driven by risk allocation consistently exceed those attributable to technological cost variations. This finding reinforces the argument that renewable energy deployment is increasingly constrained by financial and institutional factors rather than by engineering feasibility.

The magnitude of the observed effects is economically significant. Reductions in weighted average cost of capital of 150–350 basis points, as observed in projects supported by bankable power purchase agreements, materially alter project net present value and internal rates of return. In capital-intensive infrastructure projects, such changes frequently determine whether projects proceed to financial close or remain stalled at the development stage.

### 6.2 Revenue certainty as the dominant driver of bankability

Among all risk categories examined, offtake and revenue risk emerge as the most influential determinants of financing outcomes. Stable, long-term revenue arrangements reduce both the probability and severity of downside scenarios, allowing lenders to extend longer tenors and accept lower DSCR thresholds. This effect is particularly pronounced in markets with volatile wholesale prices or financially weak utilities.

The results suggest that even in mature electricity markets, full exposure to merchant risk remains challenging for large-scale renewable projects financed on a non-recourse basis. While merchant and short-term contracting structures may be viable for well-capitalized sponsors or portfolio-based investors, they significantly constrain the availability of project finance debt. This has implications for market design in systems transitioning away from long-term contracts toward more market-based remuneration mechanisms.

### 6.3 Construction risk and lender confidence

The analysis confirms that construction and completion risk, while often perceived as secondary to revenue risk, plays a critical role in shaping lender confidence and financing structure. Effective transfer of construction risk through fixed-price, date-certain EPC contracts with adequate performance security reduces uncertainty during the most vulnerable phase of the project lifecycle.

For technologies involving greater construction complexity, such as onshore wind and hybrid renewable projects, weak or fragmented EPC arrangements lead to conservative lender behavior. This manifests in higher contingency reserves, stricter covenants, and lower leverage. These findings underscore the importance of contractual clarity and counterparty strength in infrastructure projects where completion risk cannot be easily diversified.

### 6.4 Role of public risk mitigation and fiscal considerations

Public risk mitigation instruments, including partial risk guarantees and political risk insurance, are shown to be effective in mobilizing private capital in higher-risk environments. By addressing risks that private investors are unable or unwilling to bear, these instruments reduce financing costs and extend debt tenors.

However, the results also highlight the fiscal trade-offs associated with such interventions. Guarantees and insurance create contingent liabilities that may not be immediately visible in public accounts but can materialize under adverse conditions. Poorly targeted or open-ended guarantees risk transferring excessive downside exposure to the public sector without corresponding efficiency gains.

These findings support the view that public risk mitigation should be selective, transparent, and time-bound. Instruments should focus on clearly defined risks—such as utility payment default or regulatory breach—rather than broadly subsidizing project revenues.

### 6.5 Grid integration and system-level risk allocation

As renewable penetration increases, grid and curtailment risks become increasingly salient. The results indicate that unallocated or poorly compensated curtailment risk materially undermines project bankability by introducing revenue volatility that cannot be efficiently hedged by private investors.

Allocating responsibility for grid expansion and system adequacy to public authorities improves financing outcomes by aligning risk with control. Hybrid projects incorporating storage offer partial mitigation but do not fully substitute for clear regulatory frameworks governing dispatch, compensation, and access to ancillary service markets.

These findings suggest that financial risk allocation must evolve in tandem with power system transformation. Traditional project-level contracts are insufficient if system-level risks are not addressed through coordinated planning and regulation.

### 6.6 Implications for market design and investment strategy

The analysis has important implications for the design of renewable energy markets and procurement mechanisms. Competitive auctions and standardized contracts can reduce transaction costs and improve risk allocation, but only if contract terms adequately address key financial risks. Short-term price-based auctions without revenue stabilization mechanisms may achieve low headline prices but increase financing costs and limit participation.

For investors and lenders, the results highlight the importance of integrated risk assessment. Evaluating renewable energy projects requires careful consideration of contractual enforceability, institutional credibility, and system-level constraints, in addition to technology performance.

### 6.7 Distributional and developmental considerations

Optimized risk allocation has broader implications beyond financing efficiency. Lower financing costs reduce electricity prices over the long term and improve affordability for consumers. In developing economies, improved risk allocation can expand access to private capital, reduce reliance on public budgets, and accelerate infrastructure development.

However, there is also a distributional dimension to risk allocation. Transferring excessive risk to consumers through tariff adjustments or to taxpayers through guarantees can create political and social challenges. Effective risk allocation therefore requires balancing investment incentives with equity and fiscal sustainability considerations.

## 7. Conclusions and Directions for Future Research

### 7.1 Conclusions

This study examined financial risk allocation mechanisms in large-scale renewable energy infrastructure projects and evaluated their effects on project bankability, financing conditions, and private investment mobilization. The analysis demonstrates that financial risk allocation is not a secondary contractual detail but a central determinant of renewable energy investment outcomes, often exerting a stronger influence than differences in technology costs or resource quality.

The empirical results show that offtake and revenue risk dominate financing outcomes across all project typologies. Long-term, bankable power purchase agreements significantly reduce the weighted average cost of capital by stabilizing cash flows and improving lender confidence. These effects translate into higher leverage ratios, longer debt tenors, and increased volumes of private capital mobilized per unit of installed capacity. In contrast, exposure to merchant market risk substantially raises financing costs and limits access to non-recourse debt, particularly in capital-intensive projects.

Construction and completion risk also plays a critical role, especially during the early stages of the project lifecycle. The effective transfer of construction risk through fixed-price, date-certain EPC contracts with adequate performance security reduces uncertainty during the most vulnerable phase of the project and enables more efficient financing structures. This effect is especially pronounced for onshore wind and hybrid renewable projects, where construction complexity and interface risks are higher.

Regulatory, political, and grid-related risks remain decisive factors in emerging and developing economies. Public risk mitigation instruments such as partial risk guarantees and political risk insurance are shown to be effective in addressing specific market failures and mobilizing private capital in higher-risk contexts. However, these instruments involve fiscal trade-offs and must be carefully designed to avoid excessive public contingent liabilities or distorted investment incentives.

Taken together, the findings confirm that optimal financial risk allocation requires aligning risks with the parties best able to manage them while maintaining transparency, enforceability, and fiscal discipline. Well-designed risk allocation frameworks lower financing costs, expand investor participation, and accelerate the deployment of renewable energy infrastructure without undermining market efficiency.

**7.2 Policy implications**

The results have several implications for policymakers, regulators, and public institutions involved in renewable energy deployment. First, stable and credible revenue frameworks are essential for attracting long-term private capital. Governments can reduce financing costs by providing standardized, bankable contractual structures rather than relying on ad hoc support measures. Second, public intervention should focus on risks that private investors cannot efficiently manage, such as regulatory instability, utility credit risk, and system-level grid constraints. Third, transparency in the use of guarantees and other risk mitigation instruments is necessary to ensure that public support delivers genuine additionality rather than substituting for private risk-taking.

From a system perspective, the allocation of grid and curtailment risks must evolve alongside increasing renewable penetration. Clear rules governing dispatch, compensation, and network expansion are required to maintain project bankability as power systems become more complex and decentralized.

**7.3 Implications for investors and financiers**

For developers, lenders, and institutional investors, the findings underscore the importance of integrated risk assessment that extends beyond technology performance and headline tariffs. Contract enforceability, counterparty strength, regulatory credibility, and system-level constraints should be treated as core financial variables. Projects with well-structured risk allocation not only achieve lower financing costs but also attract a broader pool of investors, improving market liquidity and resilience.

The results also suggest that portfolio-based investment strategies may mitigate some project-level risks, but they do not eliminate the need for sound risk allocation at the individual project level. Non-recourse financing remains highly sensitive to contractual and institutional quality.

**7.4 Directions for future research**

Several avenues for future research emerge from this study. First, access to transaction-level financing data would allow for more granular econometric analysis of the relationship between risk allocation mechanisms and financing terms. Second, further research is needed on the evolving role of merchant exposure, corporate PPAs, and hybrid revenue models in high-renewable electricity systems. Third, the interaction between financial risk allocation and social or distributional outcomes—such as electricity affordability and fiscal sustainability—warrants deeper investigation.

Finally, as renewable energy technologies continue to integrate with storage, hydrogen, and digital systems, new forms of risk will emerge that challenge existing allocation frameworks. Understanding how financial structures adapt to these changes will be essential for sustaining investment momentum in the global energy transition.

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