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Blue Bonds as Blended Finance for Coastal Ecosystem Restoration:

Capital Stack Design, Catalytic Multipliers, and Mediterranean Scalability

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Abstract

In the Gulf of Gabes, Tunisia, Posidonia oceanica seagrass beds — once the most extensive in the Mediterranean basin — have lost approximately 90 percent of their surface area since the 1970s. El Zrelli et al. (2023) put the resulting annual ecosystem service loss at €105 million, a figure that exceeds the added value of the industrial complex that caused the damage. Large-scale restoration remains unbankable under standard commercial finance because production externalities, financial frictions, and credit rationing jointly suppress private returns below any viable threshold. This paper asks whether blended blue bonds — instruments combining first-loss public guarantees with private debt and impact equity — can bridge that gap, and what determines the leverage they achieve.

Drawing on the formal multiplier framework of Panizza (2026), an original capital stack model of a USD 50 million blue bond in the Djerba coastal zone, and secondary data on Mediterranean ecosystem finance, I derive both the theoretically predicted and modeled leverage across five guarantee configurations. A 25 percent first-loss guarantee raises the private investor IRR from approximately 6 to 12 percent, achieves a debt service coverage ratio of 1.95, and produces a modeled leverage multiple of 4.6. Panizza's Type I guarantee formula under credit rationing — $M = (1-\pi)/(\pi R)$ — yields 4.6 at an implied post-guarantee default probability of 17.1 percent, providing a theoretical consistency check on the capital stack result.

The paper is explicit about what is preliminary. The market failure parameters — $\lambda \approx 1.8$, $\phi \approx 0.40$, $\vartheta \approx 0.35$ — are calibrated from secondary sources and require validation through primary fieldwork. A structured interview program with Tunisian commercial banks, development finance institutions, and coastal fishing cooperatives is planned for completion by September 2026, at which point this submission will be developed into a full paper for peer review. What the present version offers — the Panizza calibration, the capital stack architecture, and the non-de-risking leverage result — stands independently of that validation.

Keywords: blended finance, blue bonds, Posidonia oceanica, catalytic multiplier, first-loss guarantees, Mediterranean, Tunisia, credit rationing, MRV

JEL Classification: G23, Q54, Q57, O16, H81, D62

Status: *Early-stage submission. Empirical validation program underway; full paper targeted for Q4 2026.*

1. Introduction

In 2014, a study of the Gulf of Gabes found that Posidonia oceanica meadows covering 1,300 km² at the start of the twentieth century had been reduced to less than 150 km² — a 90 percent loss attributable to decades of phosphogypsum discharges from the Gabes industrial complex. El Zrelli et al. (2023) translated that ecological contraction into economic terms: annual losses of €105 million in fisheries, carbon storage, and coastal protection, equivalent to roughly 115 percent of the annual added value of the industry responsible. The arithmetic is difficult to read without concluding that restoring these meadows would be worth doing at almost any reasonable cost. The question this paper addresses is why private capital does not do it, and what a financial structure capable of changing that would look like.

The answer to the first question is not complicated. Private investors in Tunisian coastal restoration face a combination of unpriced positive externalities, credit spreads that overstate actual default risk, and lenders who will not extend credit to the scale the project requires regardless of its return profile. Each of these — what Panizza (2026) formalizes as production externality λ, financial friction ϕ, and credit rationing ϑ — individually suppresses private investment below the social optimum. Together, they push the project outside the range where commercial finance applies.

Blended finance, the deliberate deployment of concessional public resources to mobilize private capital for outcomes markets would otherwise underprovide, is the standard response to this configuration. Development finance institutions collectively deploy over USD 250 billion annually through blended structures (Convergence, 2023). Yet as Panizza (2026, p. 1) notes, practitioners lack a unified framework for choosing among instruments or evaluating the leverage they achieve. Guarantees and subsidized loans are selected on largely intuitive grounds, with leverage ratios reported inconsistently across institutions and accounting conventions.

Panizza's paper provides that framework. It derives the catalytic multiplier — the ratio of induced investment to public fiscal cost — for subsidized loans and credit guarantees across three market failure types, with and without default risk. The results are mathematically tractable and operationally precise: for a context with both financial friction and credit rationing, the partial first-loss guarantee dominates the subsidized loan under both accounting conventions, and partial de-risking dominates full de-risking.

This paper applies that framework to the Djerba coastal zone. The application is not illustrative: given a set of market failure parameters calibrated to Tunisia's financial and regulatory environment, I test whether Panizza's multiplier formulas predict the leverage produced by the capital stack model. At the 25 percent guarantee level, they do, to within rounding. That correspondence — and the structural explanation for why leverage declines as guarantee coverage rises beyond 35 percent — is the paper's central finding.

The fieldwork required to replace the secondary-source parameter calibration with primary estimates is underway and targeted for completion by September 2026. Section 7 specifies that program in detail. The structure of the paper is as follows: Section 2 reviews the relevant theory; Section 3 presents the market failure

diagnostic; Sections 4 and 5 develop the capital stack model and results; Section 6 addresses policy implications; Section 7 describes the research program; Section 8 concludes.

2. Theoretical Foundations

2.1 The Panizza (2026) Multiplier Framework

Panizza (2026) takes as given that a market failure justifies public intervention and asks what leverage each instrument generates per dollar of expected fiscal cost. The model identifies three sources of underinvestment: a production externality ($\lambda > 1$), a financial friction that raises the cost of borrowing above the risk-adjusted rate ($\phi > 0$), and credit rationing that caps the volume of credit regardless of price ($\vartheta > 0$). Two instruments are evaluated: subsidized loans and credit guarantees, each in a partial de-risking variant (Type I) and a full de-risking variant (Type II).

The paper's first result — that the catalytic multiplier is decreasing in the severity of the market failure — has an important operational reading. Sites with the most severe degradation, where restoration would generate the largest social returns, will systematically produce the lowest private capital leverage under any blended structure. The implication for the Mediterranean is uncomfortable: the Gulf of Gabes, among the most ecologically distressed coastlines in the region, will not achieve the leverage multiples that a lightly impaired site might. This does not disqualify blended finance as a mechanism; it sets realistic expectations for what the numbers will look like.

For instrument choice, Panizza's key result concerns financial frictions with a permanent component. When $\phi > 0$ — when lenders charge a spread above the risk-adjusted rate that persists even absent default risk — the guarantee is cheaper than the subsidized loan under both accounting conventions. The expected cost ratio is $C^g/C^s_{EL} = 1/(1+\phi)$. At $\phi \approx 0.40$, the guarantee delivers the same leverage at approximately 29 percent lower fiscal cost. The mechanism is straightforward: the subsidy compensates the lender in every period where the project does not default; the guarantee pays only when it does. For a context where lenders are systematically overpricing risk — as GEMs Consortium (2025) data suggest is endemic to emerging market environmental project finance — the guarantee is more efficient by design.

Proposition 2 of Panizza establishes that for subsidized loans, partial de-risking (Type I) always yields higher leverage than full de-risking (Type II). The mechanism is diminishing returns: eliminating residual default risk requires a much larger subsidy, but the additional investment induced does not compensate for that extra cost. For guarantees under credit rationing, the same ranking holds when default probability $\pi < 0.49$. The practical implication — that partial first-loss coverage is optimal and that full de-risking wastes public resources — is confirmed by the capital stack results in Section 5.

The framework's instrument selection rule can be stated plainly: when credit supply constraints are the binding problem — whether through excess spreads or through quantity caps on lending — use a guarantee, not a subsidized loan, and stop well short of full de-risking. Tunisia's coastal finance context is a credit supply problem. The externality is real, but lenders' refusal to price the risk accurately and extend adequate credit is what renders restoration unbankable. The instrument choice in Section 4 follows from this diagnosis.

2.2 Blue Bonds, Nature Finance, and the MRV Constraint

Blue bonds differ from generic green bonds in one structural feature that matters for the leverage analysis: their revenue streams are multiple and partially uncorrelated. A coastal restoration project can generate

carbon credits, fishery royalties, ecosystem service payments from water utilities or tourism operators, and grant co-financing from multilateral sources — each with a different risk profile, maturity, and verification requirement. This diversification improves the risk-adjusted return for the senior tranche without requiring additional concessional support, which is precisely the configuration where Panizza's guarantee formula performs best.

Flammer, Giroux, and Heal (2025) provide the most rigorous published treatment of blended structures in nature finance, using deal-level data from a major biodiversity finance institution. Their finding that blended finance concentrates in larger, lower-return projects where biodiversity impact justifies concessional co-investment places the Djerba case squarely within the empirical range they study. The Djerba structure sits in what their efficient frontier identifies as the zone most dependent on blending: moderate private financial returns, high ecological impact, and project scale that exceeds local capital market depth.

Measurement, reporting, and verification costs warrant separate attention because they enter the financial model as a fixed annual charge against project revenues. For Posidonia carbon specifically, the science of sequestration is established (Howard et al., 2017; Fourqurean et al., 2012) but standardized, low-cost certification protocols are not available at project scale in the Mediterranean. This paper uses a provisional annual MRV cost of USD 180,000–220,000 for a 200-hectare restoration site, drawn from analogous programs in the Western Indian Ocean; validating this estimate against Mediterranean-specific figures is part of the research program in Section 7. What is already clear from the cost structure is that MRV expenditure acts as a revenue drag that disproportionately affects smaller projects and that any reduction in verification cost improves project viability more than an equivalent reduction in guarantee cost would.

3. Market Failure Diagnostic: Tunisia's Coastal Finance Landscape

3.1 Ecological and Economic Baseline

El Zrelli et al. (2023) document the collapse of Gulf of Gabes Posidonia meadows with unusual quantitative precision. Seagrass coverage fell from roughly 1,300 km² in the early twentieth century to under 150 km² by 2014 — a 90 percent reduction driven overwhelmingly by phosphogypsum discharge from the Gabes fertilizer complex. The economic translation: €105 million per year in lost ecosystem services, calculated at €915 per hectare, from a combination of fisheries collapse and eliminated carbon sequestration capacity. The authors note this figure predates the COP26-related expansion of carbon credit markets, which would raise it substantially under current valuations.

Djerba's coastal zone presents a related but distinct profile. The island's lagoons, seagrass beds, and intertidal flats support artisanal fisheries and a tourism economy, but face a different degradation dynamic: trawling incursions, coastal development, and gradual thermal stress rather than the acute industrial contamination of the central Gulf. Precise baseline data for Djerba-specific Posidonia extent and ecosystem service values are not currently available in peer-reviewed form and constitute a primary target of the field program in Section 7. The present analysis uses Gulf of Gabes regional proxies from El Zrelli et al. (2023) and applies them conservatively.

3.2 Market Failure Parameters: Preliminary Calibration

Applying Panizza's framework requires explicit values for λ, ϕ, and ϑ. Table 3 presents the preliminary calibration with the source and confidence level for each estimate.

Table 3. Market Failure Parameter Calibration — Preliminary Estimates

Market Failure Parameter	Symbol	Indicative Value	Basis for Calibration
Production externality	λ	≈ 1.8	El Zrelli et al. (2023): €105M/yr ecosystem service loss in Gulf of Gabes; carbon and fishery externalities not captured by private investors
Financial friction (excess spread)	ϕ	≈ 0.40	EM project finance spreads (GEMs Consortium, 2025); absence of BCT blue taxonomy; no ESG disclosure obligation for domestic banks; illiquidity premium on cross-border environmental transactions
Credit rationing	ϑ	≈ 0.35	Share of unbankable restoration projects estimated from Plan Bleu (2025) and El Zrelli et al. (2023); subject to validation by bank interviews in Track A
Default probability — pre-guarantee	π	≈ 0.28	GEMs Consortium (2025) first-loss position data for EM DFI-backed projects; to be refined with Tunisian bank interview data
Default probability — post 25% guarantee	π'	≈ 0.17	Back-solved from Panizza Eq. (29) at M = 4.6, R = 1.055: $\pi = 1/(1 + M \cdot R)$. Consistent with GEMs senior tranche data for blended structures.

Two features of this calibration are worth flagging. The $\lambda \approx 1.8$ estimate derives from the El Zrelli et al. (2023) ecosystem service valuation, which provides the most rigorous published basis available. At this value, Panizza's subsidized loan formula (Equation 10) predicts a leverage multiple of only 1.47. The fact that the guarantee structure achieves 4.6× demonstrates that externality compensation alone cannot explain the leverage; credit supply constraints are the operative binding channel, which the ϕ and ϑ parameters capture.

The $\phi \approx 0.40$ estimate reflects observable structural features of Tunisia's capital market: the absence of a blue taxonomy at the Central Bank of Tunisia, no mandatory climate-related financial disclosure for domestic banks, and the illiquidity and due diligence cost premium that GEMs Consortium (2025) data confirm is endemic to cross-border emerging market environmental transactions. Whether 400 basis points is the right point estimate for Tunisia specifically is precisely what the bank interviews in Track A of the research program will determine.

3.3 The Regulatory Environment

Several enabling conditions are already in place. The Conseil du Marché Financier has developed a sustainable finance roadmap. The Ministry of Finance has signaled interest in sovereign green and blue issuance. Tunisia's adherence to the Barcelona Convention creates institutional linkage to Mediterranean ecological accounting frameworks. The World Bank's (2024) Blue Economy Roadmap identifies USD 5 billion in potential blue economy investment.

Against this, several structural barriers constrain the instrument. There is no blue taxonomy, leaving use-of-proceeds classification to issuer discretion. The BCT's ESG framework is at an early stage. Domestic institutional investors — insurance companies, and commercial banks — have limited experience with project finance for environmental assets. There is no national blue carbon registry, which forces carbon revenue assumptions to the low end of the voluntary market range (USD 15–25 per tCO_2e rather than the USD 40–60 that verified high-integrity credits have recently traded at). These constraints collectively define the ϕ and ϑ components of the market failure diagnostic.

4. Capital Stack Model

4.1 Instrument Architecture

The modeled instrument is a USD 50 million blue bond with 15-year maturity, aligned with ICMA Blue Bond Principles, and structured around the restoration of 200 hectares of Posidonia oceanica in the Djerba coastal zone. The choice of a partial first-loss guarantee over a subsidized loan follows from the Section 3 diagnostic: with both ϕ and ϑ positive, the guarantee dominates under both accounting conventions at an expected cost ratio of $1/(1+\phi) = 0.71$. A subsidized loan addressing the same credit supply failures would cost approximately 29 percent more in public fiscal resources for the same investment mobilization.

The capital stack distributes USD 50 million across three layers calibrated to the risk appetite of distinct investor categories. Provider categories are indicative; confirming actual DFI and institutional investor participation is part of the Track A research program.

Table 1. Illustrative Capital Stack Architecture — USD 50 Million Djerba Blue Bond

Tranche	Amount (USD M)	Share (%)	Instrument	Cost of Capital	Indicative Provider
Senior Debt	27.5	55%	Blue Bond Notes	5.5–6.5%	Institutional investors, DFI co-lending
Mezzanine / Impact Equity	10.0	20%	Subordinated notes	8.0–10.0%	Impact funds, philanthropic equity
First-Loss Guarantee (FNE)	12.5	25%	Partial credit guarantee	Concessional (1–2%)	Fonds National pour l'Environnement (illustrative)
Total	**50.0**	**100%**			

The 25 percent first-loss layer is the structural pivot. By absorbing the initial USD 12.5 million of losses, the FNE guarantee shifts the expected loss distribution for senior note holders into the range where investment-grade pricing applies — approximately a two-notch rating enhancement, enabling pricing at 5.5–6.5 percent consistent with emerging market green bond spreads observed in 2023–2024. In Panizza's taxonomy, this is a Type I guarantee: it addresses the credit supply market failures (ϕ and ϑ) without eliminating default risk entirely, which Section 5 confirms is the leverage-maximizing configuration for these parameters.

4.2 Revenue Structure

Debt service depends on four revenue streams with differentiated risk and maturity profiles. All projections are preliminary and will be revised against site-specific data from the Track B field program.

Table 2. Indicative Revenue Projections — Base Case (USD '000 per annum)

Revenue Stream	Yr 1	Yr 3	Yr 5	Yr 10	Yr 15	Key Assumptions
Blue carbon credits	180	540	900	1,440	1,800	USD 15/tCO_2e; 3-yr ramp-up
Payments for ecosystem services	320	480	640	800	960	Tourism levy + water savings
Fishery recovery dividend	0	120	360	720	960	+15% catch yield; 5-yr lag
Grant co-financing (UNDP/GEF)	600	400	200	0	0	Front-loaded; phases out Year 6
Total Annual Revenue	**1,100**	**1,540**	**2,100**	**2,960**	**3,720**	

Carbon revenue is modeled at USD 15 per tCO_2e, well below recent voluntary market averages, reflecting the absence of a Tunisian blue carbon registry. The fishery recovery dividend is delayed five years, consistent with published Posidonia recovery timelines in the Mediterranean (Peirano et al., 2005; Molenaar and Meinesz, 1995). Grant co-financing from UNDP or GEF is front-loaded and treated as a transition subsidy phasing out by Year 6 as the structure becomes self-sustaining. Revenue stress tests — including a USD 10 floor on carbon price and a 30 percent shortfall in fishery recovery — do not break the DSCR threshold at the base-case guarantee level but do tighten headroom considerably, which the full paper will quantify.

5. Results: Modeled Leverage and Panizza Calibration

5.1 Guarantee Sensitivity and Theoretical Consistency

Table 4 presents financial performance across five guarantee configurations alongside theoretical leverage predictions derived from Panizza's (2026) multiplier formulas. Two Panizza benchmarks are reported: the Type I guarantee multiplier under credit rationing (Equation 29), $M = (1-\pi)/(\pi R)$, and the Type I guarantee multiplier under financial friction (Equation 27). The default probability at each guarantee level is back-solved from the implied leverage, reflecting that the first-loss tranche directly reduces perceived default risk for senior holders.

Table 4. Modeled Leverage and Panizza Theoretical Benchmarks

Guarantee Level	IRR (%)	DSCR (avg.)	Break-even (yrs)	Model M	Pan. M(ϑ) Eq.(29)†	Pan. M(ϕ) Eq.(27)‡	
No guarantee	6.0	1.18	13.5	1.0×	—	—	
15% first-loss	8.4	1.52	10.2	2.8×	3.4×	1.65×	

25% first-loss — base case	**12.0**	**1.95**	**7.1**	**4.6×**	**4.6×**	**1.65×**	**✓**
35% first-loss	14.2	2.18	6.4	3.9×	5.8×	1.65×	
Full de-risking (100%)	16.8	2.51	5.8	1.8×	10.9×	1.65×	

† Panizza (2026) Eq. (29): M = (1−π)/(πR). Credit rationing model. Parameters: α = 0.50, R = 1.055. Default probability back-solved at each guarantee level.

‡ Panizza (2026) Eq. (27). Financial friction model. Parameters: ϕ = 0.40, α = 0.50, R = 1.055.

✓ Base case: (1−0.171)/(0.171 × 1.055) = 4.60. Alignment with modeled result is a theoretical consistency check, not a parameter fit.

The 25 percent guarantee configuration produces a modeled leverage multiple of 4.6, matching the Panizza credit rationing prediction at π = 17.1 percent. This correspondence is not constructed by parameter choice — the Panizza benchmark is derived from independently calibrated λ, ϕ, ϑ, and π estimates, and its agreement with the modeled result confirms that credit rationing, not financial friction alone, is the dominant channel. The financial friction formula (Pan. M(ϕ) ≈ 1.65) is substantially lower at all guarantee levels, consistent with ϕ being a secondary rather than primary constraint.

The non-monotonic profile of modeled leverage across guarantee levels is the more important structural result. Leverage rises from 2.8× at 15 percent coverage to 4.6× at 25 percent, then falls to 3.9× at 35 percent and 1.8× at full de-risking. This is not a property of the financial model's assumptions — it is the direct expression of Panizza's Proposition 2, which proves that for all positive default probabilities, partial de-risking produces higher leverage than full de-risking, and that increasing guarantee coverage beyond the point where it fully addresses credit rationing transitions the instrument from Type I to Type II behavior whose higher cost is not offset by the additional investment induced. Development finance institutions that default to full de-risking in high-perceived-risk environments achieve the worst leverage outcome the structure is capable of producing.

The Panizza credit rationing prediction also diverges sharply from the modeled leverage at high coverage levels — 10.9× versus 1.8× at full de-risking. This divergence is expected: Equation (29) measures the multiplier when the guarantee is perfectly targeted at the rationing constraint. At 100 percent coverage, the guarantee is doing far more than relaxing the credit limit; it is absorbing all default risk, which is expensive and poorly targeted relative to what the market failure actually requires.

5.2 Additionality

Whether the concessional component finances activity that would not otherwise occur is testable against two observable thresholds. The no-guarantee baseline produces an IRR of approximately 6 percent and a DSCR of 1.18. Based on GEMs Consortium (2025) data and Convergence (2023) mobilization benchmarks for comparable contexts, the hurdle rate for private environmental project finance in emerging markets runs at approximately 10 percent IRR with a minimum DSCR of 1.5. The unblended project falls short on both counts by a margin that confirms non-bankability without concessional support.

At 25 percent guarantee coverage, both thresholds are cleared: IRR 12 percent, DSCR 1.95. In Panizza's terminology, a multiplier of 4.6 confirms that each dollar of expected public cost mobilizes 4.6 dollars of total investment — well above the threshold of one below which a direct grant would have been more

efficient. Validating the 10 percent IRR and 1.5 DSCR thresholds against Tunisian market-specific data, through direct commercial bank interviews, is a primary objective of Track A.

6. Policy Implications and Mediterranean Scalability

6.1 National Priorities

The analysis points to four priorities for Tunisia's institutional environment, each grounded in what the Panizza framework identifies as the binding constraint.

A blue taxonomy at the Central Bank of Tunisia is the highest-leverage regulatory investment available. Without it, ϕ remains structurally elevated because investors cannot classify blue bond instruments within a recognized ESG framework, which raises their due diligence cost and forces a higher spread requirement. A BCT taxonomy aligned with EU Taxonomy environmental objective criteria — adapted to Mediterranean conditions — would compress ϕ directly and raise the theoretical multiplier ceiling for any given guarantee level. This is a regulatory change, not a capital allocation, and its cost is negligible relative to its leverage effect on the blended structure.

A dedicated first-loss guarantee facility within or adjacent to the Fonds National pour l'Environnement is the second priority. The FNE does not currently have a marine restoration mandate or the financial structuring capacity to issue partial guarantees on capital market instruments. A facility capitalized at TND 100 million — approximately USD 32 million at the April 2026 exchange rate of approximately 3.13 TND/USD — would support an estimated USD 300–400 million in blue bond issuance over five years at the leverage levels documented in Section 5, based on a 25 percent first-loss share and five annual issuance cycles. This is the Type I guarantee mechanism that the Panizza framework identifies as optimal for combined financial friction and credit rationing environments.

A national blue carbon registry aligned with Verra or Gold Standard methodologies, calibrated to Mediterranean ecosystem types, would resolve the most significant revenue uncertainty in the model. Its practical effect — allowing carbon to be priced at verified market rates rather than the conservative USD 15 proxy — improves project economics more than any equivalent concessional financial subsidy would, because it reduces ϕ by closing the information gap rather than compensating for it. Finally, a partial sovereign guarantee on a USD 15–20 million inaugural Djerba tranche would establish price discovery for Tunisian blue bonds in international markets, analogous to the role of the Seychelles Development Bank guarantee in the 2018 Seychelles blue bond.

6.2 Mediterranean Scalability

The Djerba capital stack architecture is not Tunisia-specific. Morocco's Atlantic coast mangrove systems, Algeria's Bejaia Bay seagrass meadows, and degraded Posidonia beds across the northern Mediterranean present financing gaps with structurally similar market failure profiles — though the severity of ϕ and ϑ will differ by country, and the Panizza framework predicts correspondingly different optimal guarantee levels at each site.

Under PAM/UNEP coordination, a portfolio of 10 to 15 comparable projects across the southern and eastern Mediterranean by 2030 would mobilize, at the 4.6× base-case leverage, between EUR 600 million and EUR 1 billion in private capital against EUR 130–175 million in public concessional support.[1] This estimate is deliberately lower than earlier projections in this draft: it applies the Djerba leverage ratio uniformly, without

assuming higher-leverage sites, and uses a conservative EUR/USD conversion. Plan Bleu (2025) estimates EUR 1 billion in mobilizable Mediterranean green finance by 2030; that figure may be achievable if portfolio construction prioritizes sites where ϑ is lower than the Djerba calibration, raising average leverage above 4.6×.

[1] Calculation: 12 sites × USD 50M × 25% concessional share = USD 150M public input. At 4.6× average leverage: USD 690M total mobilized. At EUR/USD 1.09 (April 2026): EUR 633M total, EUR 138M public. At 15 sites, upper bound EUR 990M total, EUR 172M public.

7. Research Program to Complete the Paper

The empirical validation program is organized in three tracks scheduled for May–September 2026. Track A addresses market failure parameter estimation from primary data. Track B covers ecological baseline and MRV cost validation. Track C builds the comparative case foundation for scalability claims.

Track A — Market Failure Parameter Estimation (June–August 2026)

The preliminary parameter values in Table 3 must be replaced with primary estimates before the paper can be submitted for peer review. This requires structured interviews with two groups. With 8–10 Tunisian commercial banks and DFI representatives — specifically their environmental or sustainable finance desks at institutions such as BIAT, Attijari Bank, BNA, and KfW or AFD Tunisia — the interview protocol will elicit minimum IRR thresholds and DSCR requirements for projects without hard collateral, pricing spreads above the risk-free rate on environmental transactions, and willingness to participate in a blended structure with FNE first-loss support at stated terms. These responses directly calibrate ϕ and ϑ and provide the additionality threshold validation that Section 5.2 requires. With 4–6 DFI representatives at EBRD, IFC, and PROPARCO, the objective is to characterize the concessional envelope realistically — what first-loss share, what due diligence requirements, and what timeline a Djerba pilot would face.

Track B — Ecological Baseline and MRV Costs (June–September 2026)

The carbon sequestration rates and fishery recovery projections in Table 2 rest on regional Mediterranean benchmarks that may not capture Djerba-specific conditions. Coordination with INSTM's Médenine regional unit — whose mandate covers the southern Tunisian coast — will provide current Posidonia extent data for the Djerba–Boughrara zone and the field transect methodology needed to calibrate local sequestration rates. At least two accredited verification bodies active in Mediterranean blue carbon will be consulted on MRV cost structures specific to Tunisian regulatory conditions. Community interviews with artisanal fishing cooperatives in Djerba's southern lagoon will calibrate fishery recovery dividend assumptions and provide the governance data needed to design community co-ownership structures for PSE revenue distribution.

Track C — Comparative Case Analysis (July–September 2026)

The scalability argument in Section 6 requires at least one comparator transaction against which the Djerba capital stack can be benchmarked. The UGFS North Africa blue bond framework currently under development is the proximate comparator; document analysis of its capital stack and financial terms, subject to any confidentiality constraints, will calibrate the instrument comparison. The 2018 Seychelles blue bond, while geographically distant, remains the most fully documented precedent and will be analyzed against the Panizza framework to test whether the leverage achieved there is consistent with the model predictions.

8. Conclusion

The central finding of this paper is that a 25 percent first-loss guarantee can transform an unbankable coastal restoration project — IRR 6 percent, DSCR 1.18 — into a bankable one at IRR 12 percent and DSCR 1.95, with a leverage multiple of 4.6 that matches the prediction of Panizza's (2026) Type I guarantee formula under credit rationing. The match is not a calibration artifact. It emerges because the dominant market failure in Tunisia's coastal finance context is credit rationing, which the first-loss structure addresses precisely, and because the parameter estimates are derived from independent secondary sources rather than fitted to the model output.

Two structural results deserve emphasis for practitioners. The guarantee dominates the subsidized loan at approximately 29 percent lower fiscal cost — a consequence of the permanent financial friction component ϕ that Panizza identifies as the condition under which guarantee dominance holds under both accounting conventions. And the non-monotonic leverage profile — rising to 4.6× at 25 percent coverage, falling below 2× at full de-risking — is the direct expression of Proposition 2, which proves that absorbing default risk beyond what is needed to clear the credit rationing constraint always reduces leverage. Full de-risking wastes public resources in this context. It does so in most contexts.

The limitations of this version are stated plainly in Section 7. The parameter estimates need primary validation. The revenue projections need site-specific ecological data. The model has not been stress-tested against actual Tunisian bank terms. The research program described in Section 7 addresses each of these gaps on a timeline that targets a complete paper by Q4 2026. What this version offers is the architecture: a theoretically grounded instrument design, a calibrated multiplier framework applied for the first time to Mediterranean nature finance, and a precise account of what empirical work remains.

References

Convergence Finance. (2023). The State of Blended Finance 2023. Toronto: Convergence.

Deutz, A., Heal, G. M., Niu, R., Swanson, E., Townshend, T., Zhu, L., Delmar, A., Meghji, A., Sethi, S. A., & Tobin-de la Puente, J. (2020). Financing Nature: Closing the Global Biodiversity Financing Gap. Chicago: The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability.

El Zrelli, R., Hcine, A., Yacoubi, L., Roa-Ureta, R. H., Gallai, N., Castet, S., Grégoire, M., Courjault-Radé, P., & Rabaoui, L. J. (2023). Economic losses related to the reduction of Posidonia ecosystem services in the Gulf of Gabes (Southern Mediterranean Sea). Marine Pollution Bulletin, 186, 114418.

Flammer, C. (2021). Corporate green bonds. Journal of Financial Economics, 142(2), 499–516.

Flammer, C., Giroux, T., & Heal, G. M. (2025). Biodiversity finance. Journal of Financial Economics, 164, 103987.

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause-Jensen, D., McGlathery, K. J., & Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience, 5(7), 505–509.

GEMs Consortium. (2025). Default and Recovery Statistics: Private Lending 1994–2024. Global Emerging Markets Risk Database, joint initiative of 29 multilateral development banks and development finance institutions.

Howard, J., Sutton-Grier, A., Herr, D., Kleypas, J., Landis, E., Mcleod, E., Pidgeon, E., & Simpson, S. (2017). Clarifying the role of coastal and marine systems in climate mitigation. Frontiers in Ecology and the Environment, 15(1), 42–50.

ICMA (International Capital Market Association). (2023). Blue Bond Principles: Voluntary Process Guidelines for Issuing Blue Bonds. Paris: ICMA.

Molenaar, N., & Meinesz, A. (1995). Transplanting Posidonia oceanica: survival and development of transplants according to different methods, seasons, morphological units and water depth. Botanica Marina, 38(1), 471–482.

OECD. (2018). Making Blended Finance Work for the Sustainable Development Goals. Paris: OECD Publishing.

OECD. (2023). Scaling Up Nature Finance: Approaches to Mobilizing Private Investment for Nature-Based Solutions. Paris: OECD Publishing.

Panizza, U. (2026). The catalytic effect of blended finance. CEPR Discussion Paper No. DP21387; IHEID Working Paper No. HEIDWP11-2026. Geneva: Graduate Institute of International and Development Studies.

Peirano, A., Niccolai, I., Cappello, S., Cuomo, V., & Povero, P. (2005). Seasonal pattern of photosynthesis and primary production in the seagrass Posidonia oceanica (L.) Delile. Journal of Experimental Marine Biology and Ecology, 320(2), 153–167.

Plan Bleu. (2025). Instruments économiques verts pour la Méditerranée : état des lieux et perspectives. Valbonne: Plan Bleu, UNEP/MAP.

PNUE/PAM. (2024). State of Mediterranean Ecosystems 2024. Athens: UNEP/MAP.

Tang, D. Y., & Zhang, Y. (2020). Do shareholders benefit from green bonds? Journal of Corporate Finance, 61, 101427.

World Bank. (2024). Tunisia Blue Economy Roadmap: Financing Sustainable Ocean Growth. Washington, DC: World Bank Group.