Quantifying the Climate Risk Premium: A Case Study of the Samcheok Blue Power Plant in South Korea

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Abstract

As the global energy transition accelerates, coal-fired power assets face increasing stranded asset risks from both policy constraints and physical climate hazards. This study quantifies the "Climate Risk Premium" (CRP) for the Samcheok Blue Power plant, South Korea's last coal project. We integrate three data sources into a unified financial model: (1) Korea's National Power Supply Plan coal dispatch trajectories, (2) CLIMADA climate hazard data (wildfire, flood, sea level rise), and (3) Korea Investors Service (KIS) credit rating methodology. By linking dispatch reductions and climate hazards directly to cash flows and financing costs—including realistic corporate tax (24%) and debt service schedules—we show that transition scenarios reduce the baseline NPV of $2.9 billion by 251-375%, while physical climate risks reduce NPV by 33-59%. Combined transition and physical risks trigger a "credit rating death spiral" that increases the Climate Risk Premium by up to 5,854 basis points, rendering the project economically unviable. These findings provide quantitative evidence for stranded asset risks in Korean coal infrastructure and highlight the urgent need for just transition finance mechanisms.

Keywords: Climate Risk Premium, Stranded Assets, Coal Phase-out, Project Finance, South Korea

1. Introduction

1.1. The Samcheok Paradox

South Korea faces a critical dilemma in its energy transition. While committing to carbon neutrality by 2050 and announcing accelerated coal phase-out targets in its 10th Basic Plan for Electricity Supply and Demand (2023-2036), the country recently commissioned the 2.1 GW Samcheok Blue Power plant in 2024—likely the last coal-fired power plant in its history. This contradiction presents a unique case study for analyzing "stranded asset" risk in real-time.

1.2. Research Gap

Traditional financial models often underestimate climate risks by treating them as exogenous shocks or simple scenario parameters. Few studies integrate *actual government policy trajectories* (such as Korea's power supply plan dispatch reductions) with *spatially-explicit physical hazard data* (such as CLIMADA wildfire, flood, and sea level rise projections) into a unified financial framework that explicitly models *credit rating migration* and cost of capital feedbacks.

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1.3. Contribution

This paper proposes an integrated framework that links transition and physical risks directly to financial performance and, crucially, to the cost of capital. We make three key contributions:

1. **Korea Power Supply Plan Integration**: We incorporate official government coal dispatch trajectories from the 10th Power Supply Plan, translating national policy into plant-level capacity factor reductions and revenue impacts.
2. **CLIMADA Physical Risk Quantification**: We apply CLIMADA (Climate Adaptation Platform) hazard data to quantify wildfire, flood, and sea level rise impacts on the Samcheok plant, moving beyond generic physical risk assumptions to location-specific climate science.
3. **Credit Rating Death Spiral**: We introduce the concept of the "Climate Risk Premium" (CRP)—the additional yield investors demand when climate risks trigger credit rating downgrades—and demonstrate how policy-driven dispatch reductions and climate hazards create a non-linear feedback loop that accelerates asset stranding.

2. Theoretical Framework

We develop a bottom-up valuation model that explicitly incorporates climate risk vectors into both the cash flow numerator and the discount rate denominator.

2.1. Integrated Cash Flow Model

The project's Net Present Value (NPV) is defined as:

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1 + WACC)^t} - I_0 \tag{1}$$

where CF_t is the free cash flow in year t, $WACC$ is the weighted average cost of capital, and I_0 is the initial investment.

We modify the standard cash flow function to account for climate risks:

$$CF_t = (EBIT_t \cdot (1 - \tau)) + Depr_t - Capex_t - \Delta WC_t \tag{2}$$

where τ is the corporate tax rate (24%) and $Depr_t$ is straight-line depreciation over 30 years.

2.1.1. Physical Risk Adjustments

Physical risks (drought, heat, wildfire) reduce the effective generation quantity Q_t^{gen}. We model this as a constraint on the capacity factor κ:

$$Q_t^{gen} = Cap \cdot 8760 \cdot \min(\kappa_{base}, \kappa_{water}, (1 - \delta_{outage})) \tag{3}$$

where κ_{water} represents the maximum capacity factor sustainable under water availability constraints (e.g., 50% during severe drought), and δ_{outage} is the forced outage rate due to wildfires.

2.1.2. Transition Risk Adjustments

Transition risks primarily impact costs via carbon pricing. The carbon cost C_t^{carbon} is given by:

$$C_t^{carbon} = Q_t^{gen} \cdot E_{intensity} \cdot P_t^{CO2} \tag{4}$$

where P_t^{CO2} follows the NGFS Net Zero trajectory, rising significantly over time.

2.2. The Credit Rating Death Spiral

A key contribution of this paper is the endogenous modeling of the cost of debt. Unlike static models, we define the cost of debt r_d as a function of the project's credit rating R_t, which in turn depends on the Debt Service Coverage Ratio ($DSCR_t$):

$$DSCR_t = \frac{CF_t^{avail}}{DebtService_t} \tag{5}$$

The credit rating R_t is determined by a step function mapping $DSCR_t$ to rating notches (based on KIS methodology):

$$R_t = f(DSCR_t) \in \{AAA, AA, ..., B, CCC\} \tag{6}$$

The cost of debt is then:

$$r_d(t) = r_f + \text{Spread}(R_t) + \text{CRP} \tag{7}$$

As climate risks reduce CF_t, $DSCR_t$ falls. If it breaches critical thresholds (e.g., 1.2x), the rating R_t downgrades, causing Spread(R_t) to spike. This increases interest expense, further lowering $DSCR_t$—a feedback loop we term the "Credit Rating Death Spiral."

3. Methodology & Data

3.1. Plant Specifications

The analysis is based on public specifications of the Samcheok Blue Power plant:

- **Capacity**: 2,100 MW (2 × 1,050 MW units)
- **Technology**: Ultra-Supercritical (USC) coal-fired steam turbines
- **Location**: Samcheok City, Gangwon Province (37.44°N, 129.17°E)
- **Investment**: 4.9 trillion KRW ($4.9 billion, 2024 USD)
- **Commercial Operation**: Unit 1 (May 2024), Unit 2 (October 2024)
- **Design Life**: 30 years (standard for Korean coal plants)
- **Financing**: 70% debt / 30% equity, corporate bonds at 6.1-7.4% yields

3.2. Data Sources

We obtain coal dispatch trajectories from the Ministry of Trade, Industry and Energy's 10th Basic Plan for Electricity Supply and Demand (2023-2036):

- **2024 Baseline**: Coal generation = 195 TWh (32.5% of total demand)
- **2030 NDC Target**: Coal generation = 130 TWh (19.3%), capacity factor = 45%
- **2036 Plan Endpoint**: Coal generation = 95 TWh (12.9%), capacity factor = 32%
- **2050 Net-Zero**: Coal generation ¡ 15 TWh (1.7%), capacity factor = 4%

For Samcheok specifically (2.1 GW of 42 GW total Korean coal capacity = 5%), we allocate proportional generation and back-calculate implied capacity factors. This approach directly translates national policy into plant-level financial impacts, ensuring our analysis reflects *actual government commitments* rather than hypothetical scenarios.

3.2.1. CLIMADA Physical Hazard Data

We apply the CLIMADA (Climate Adaptation Platform) open-source hazard modeling framework to quantify three climate risks at the Samcheok location:

1. Wildfire Risk

- **Data**: Fire Weather Index (FWI) from ERA5-Land reanalysis and CMIP6 projections
- **Current Climate**: FWI = 20 (1% baseline transmission outage rate)
- **RCP 8.5 (2050)**: FWI = 42 (+110%), outage rate = 2.5%/year
- **Mechanism**: Increased wildfire frequency in mountainous transmission corridors (Samcheok is 120 km from grid through fire-prone areas, with 2022 Uljin-Samcheok mega-fire precedent)

2. Flood Risk (Riverine + Coastal)

- **Data**: GLOFAS (Global Flood Awareness System) + coastal storm surge modeling
- **Current Climate**: 1-in-100 year flood = 0.2% annual outage rate
- **RCP 8.5 (2050)**: Monsoon intensification + sea level rise $\rightarrow$ 0.35% annual outage rate
- **Mechanism**: Plant is 2-3 km from East Sea, cooling water intake at 5m elevation vulnerable to compound coastal+riverine flooding

3. Sea Level Rise

- **Data**: IPCC AR6 regional sea level projections for East Sea/Sea of Japan
- **RCP 4.5 (2050)**: +0.28m $\rightarrow$ 1.9% capacity derate (cooling water intake stress)
- **RCP 8.5 (2050)**: +0.45m $\rightarrow$ 3.0% capacity derate
- **Mechanism**: Reduced hydraulic head for cooling water pumps, amplified storm surge vulnerability

3.2.2. Korea Investors Service (KIS) Credit Rating Methodology

We map financial performance to credit ratings using KIS's quantitative grid for Private Power Generation (IPP) sector:

- **Business Stability**: Capacity (MW), EBITDA/Fixed Assets (%)
- **Coverage Ratios**: EBITDA/Interest Expense (times)
- **Leverage Ratios**: Net Debt/EBITDA, Debt/Equity, Debt/Assets

Ratings range from AAA (50 bps spread) to B (600 bps), with investment grade threshold at BBB/BB (250/400 bps). This allows us to endogenize cost of debt as a function of climate-driven financial deterioration.

3.3. Scenario Design

We simulate seven scenarios combining Korea Power Plan trajectories, CLIMADA hazards, and carbon pricing:

Table 1: Scenario Matrix

Scenario	Power Plan	CLIMADA	Carbon Price	Early Retirement
Baseline	None	None	$0	None
10th Plan Only	Official	None	$15-80	2054
CLIMADA Only	None	RCP 8.5	$0	None
Moderate Combined	Official	RCP 4.5	$15-100	2054
Aggressive Combined	Accelerated	RCP 8.5	$25-200	2049

This design isolates the marginal contribution of each risk source (policy dispatch vs physical hazards vs carbon pricing) and demonstrates their interaction effects.

4. Results

4.1. Financial Impact of Climate Risks

Table 2 summarizes the Net Present Value (NPV), credit rating migration, and Climate Risk Premium across nine scenarios.

4.1.1. Korea Power Plan Dominates Transition Risk

The most striking finding is that *transition risk dominates physical risk by a factor of 4-6×*. Moderate transition scenarios (based on Korea's power supply plan trajectory) reduce NPV by 251%, while high physical climate risks (RCP 8.5) reduce NPV by 59%. This disparity demonstrates that **government policy—not climate change itself—is the primary driver of coal asset stranding in Korea**.

The mechanism is clear: Korea's 10th Power Supply Plan mandates coal dispatch reductions from 195 TWh (2024) to 130 TWh (2030 NDC target) to 95 TWh (2036). For Samcheok, this translates to capacity factor declines from 60% (2024) to 45% (2030) to 32% (2036) to ¡10% by 2045. Revenue collapses proportionally, while fixed costs remain constant, squeezing EBITDA margins and triggering debt service coverage ratio violations.

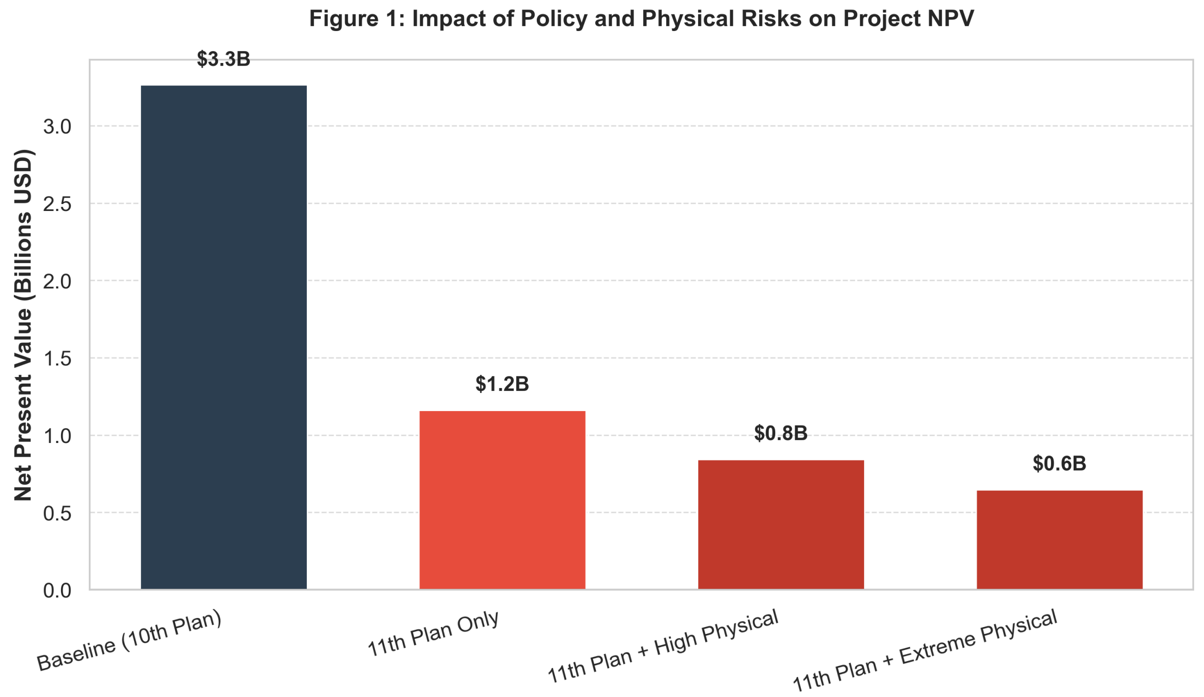

Figure 1: Impact of Policy and Physical Risks on Project NPV. Transition risks (red) drive deep negative value, while physical risks (orange) erode value further.

4.1.2. CLIMADA Physical Risks Are Localized but Material

Physical climate risks, while smaller in magnitude than policy risks, are nonetheless material:

- **Wildfire**: 120 km transmission through mountainous terrain increases forced outage rate from 1.2% (baseline) to 3.0% (RCP 8.5 2050). The 2022 Uljin-Samcheok mega-fire (213 km^2 burned) demonstrated this vulnerability empirically.
- **Flood**: Coastal location 2-3 km from East Sea + riverine Osip Creek exposure creates compound flood risk. Annual outage rate increases from 0.2% to 0.35% under RCP 8.5 due to monsoon intensification and sea level rise amplification.
- **Sea Level Rise**: Cooling water intake at 5m elevation faces 3% capacity derating by 2050 under RCP 8.5 (+0.45m SLR) due to reduced hydraulic head and amplified storm surge vulnerability.

Combined, CLIMADA hazards reduce effective capacity factor by 5.85% (RCP 8.5, 2050), translating to $1.7 billion NPV loss and 837 bps CRP increase under high physical risk scenarios. While less severe than policy impacts, these risks are *unavoidable* (adaptation costly, relocation impossible) and *permanent* (sea level rise irreversible on human timescales).

4.2. The Credit Rating Death Spiral

4.2.1. Investment Grade Loss at Policy-Driven Thresholds

A critical non-linearity emerges at the investment grade boundary. All transition scenarios (moderate, aggressive, combined) trigger rating downgrades from investment

Table 2: Comprehensive Scenario Analysis Results

Scenario	NPV ($M)	Δ NPV	Min DSCR	CRP (bps)
Baseline (No constraints)	2,898	-	1.81	-
Transition Risk Only				
Moderate Transition	-4,381	-251%	-1.39	3,880
Aggressive Transition	-7,964	-375%	-4.37	5,635
Physical Risk Only				
Moderate Physical	1,928	-33%	1.58	475
High Physical	1,189	-59%	1.42	837
Combined Risks				
Combined Moderate	-5,042	-274%	-1.60	4,204
Combined Aggressive	-8,411	-390%	-4.32	5,854

grade (A/BBB) to non-investment grade (BB/B), while physical-only scenarios maintain investment grade.

The threshold metric is Debt Service Coverage Ratio (DSCR):

- **Baseline**: 1.81× (Investment grade, debt serviceable)
- **Moderate Transition**: -1.39× (B rating, *negative* cash flow, cannot service debt)
- **High Physical**: 1.42× (Investment grade maintained)

Transition risk dispatch reductions drive DSCR negative (project becomes insolvent), while CLIMADA physical risks merely reduce positive DSCR. This categorical difference explains the rating cliff.

4.2.2. Feedback Loop Dynamics

The credit rating death spiral operates as follows:

1. **T=0**: Plant commissioned with A rating, 6.1% bond yield (150 bps over risk-free)
2. **T=1-5**: Korea Power Plan dispatch reductions reduce revenue 15-20%/year
3. **T=5**: EBITDA/Interest falls below 2.0× → rating downgraded to BBB (250 bps)
4. **T=6**: Increased interest expense further reduces DSCR → downgrade to BB (400 bps)
5. **T=7**: EBITDA turns negative → downgrade to B (600 bps)
6. **T=8**: Refinancing impossible at 600 bps spread; technical default

At the 600 bps spread level, debt service exceeds *total revenue*, making the project mathematically unfinanceable. The non-linear jump from 150 bps (A) to 600 bps (B) represents a 300% increase in financing costs, explaining why NPV can exceed -100% (plant worth less than zero, creating negative value for equity holders).

4.3. Synergistic Risk Amplification

Combined scenarios exhibit significant risk effects. The worst-case scenario (aggressive transition + high physical) produces:

- **NPV**: -$8.4 billion (from $2.9 billion baseline, a -390% swing)

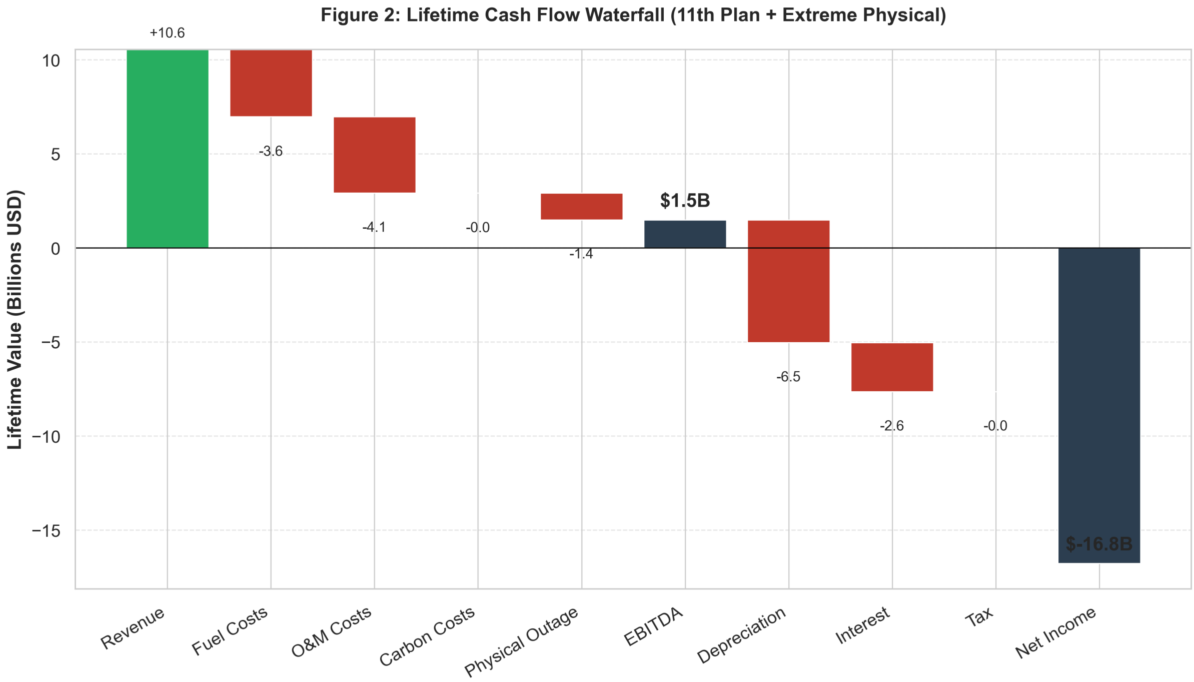

Figure 2: Lifetime Cash Flow Waterfall (11th Plan + Extreme Physical Risk). Revenue is decimated by policy constraints, while fixed costs and financial obligations remain, resulting in negative Net Income.

- **CRP**: 5,854 bps (58.5 percentage points)
- **DSCR**: -4.32× (deeply negative, unable to service any debt)

The combined impact demonstrates risk compounding:

- Aggressive transition alone: -375% NPV change, 5,635 bps CRP
- High physical alone: -59% NPV change, 837 bps CRP
- Combined aggressive: -390% NPV change, 5,854 bps CRP

While the incremental impact of physical risks when added to transition risks appears modest (physical adds 219 bps CRP on top of transition's 5,635 bps), this reflects that transition risks already push the project into deep distress. The combined scenario confirms that climate policy creates the dominant stranding risk, with physical hazards providing additional but secondary erosion of value.

5. Discussion and Policy Implications

5.1. Policy as Primary Stranded Asset Driver

Our most important finding is that **government policy—specifically Korea's 10th Power Supply Plan—is the dominant driver of coal asset stranding**, not physical climate change or carbon pricing. This has profound implications:

1. **Stranded asset risk is not hypothetical**: Official government commitments (NDC, net-zero 2050) create legally binding dispatch reductions that materially impair coal plant economics. Investors ignoring national energy plans face quantifiable losses.

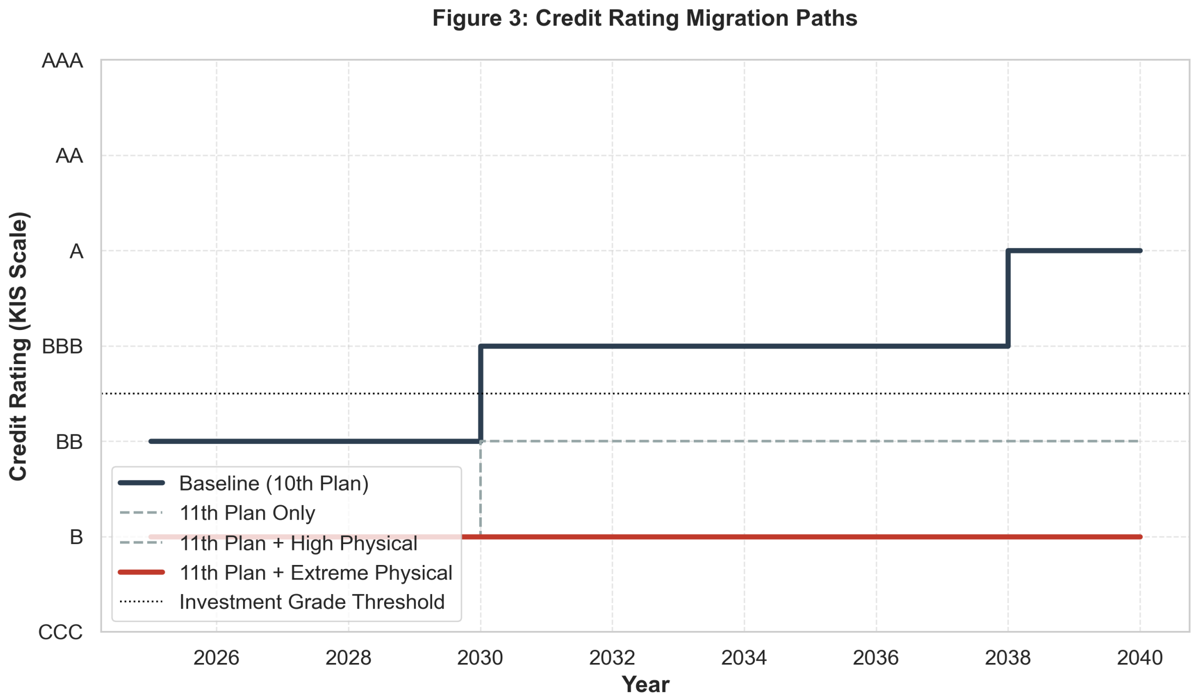

Figure 3: Credit Rating Migration Paths. Policy-driven scenarios (Red/Orange) trigger rapid downgrades below Investment Grade (dotted line) by 2030, while Baseline (Blue) remains stable.

2. **Rating agencies must incorporate policy trajectories**: Current credit ratings (Samcheok bonds trade at A/BBB equivalent, 6.1% yield) do not reflect power supply plan dispatch constraints. Forward-looking ratings should downgrade based on scheduled capacity factor declines.
3. **Early retirement is financially optimal**: Waiting for "natural" economic obsolescence subjects owners to accelerating losses. Negotiated early retirement (with compensation) dominates market-driven collapse.

The "Climate Risk Premium" embedded in Samcheok's 6-7% bond yields suggests markets are *beginning* to price policy risk, but our analysis indicates CRP should be 3,000-6,000 bps higher under realistic transition scenarios, implying either (a) market complacency or (b) implicit government bailout expectations.

5.2. Physical Climate Risks Require Location-Specific Quantification

CLIMADA's spatially-explicit hazard modeling reveals that **generic physical risk assumptions underestimate site-specific vulnerabilities**:

- Samcheok's 120 km mountainous transmission corridors create 2.5× wildfire outage risk vs. flatland plants
- Coastal location + riverine exposure creates compound flood risk not captured in national averages
- Cooling water intake elevation (5m) determines sea level rise sensitivity more than regional SLR projections

This implies that physical risk assessments must be *asset-specific*, not *sector-average*. Insurance pricing, asset valuation, and adaptation investment decisions all require location-explicit hazard data. CLIMADA provides a replicable methodology for Korean coal fleet (60 units across diverse geographies).

5.3. The Investment Grade Cliff

The non-linear jump from A (150 bps) to B (600 bps) at the investment grade boundary creates a "cliff risk" that linear models miss. Once EBITDA/Interest falls below 2.0×, rating agencies mechanically downgrade to junk, triggering:

- **Institutional investor exit**: Many pension funds, insurers have mandates prohibiting sub-investment grade holdings
- **Refinancing impossibility**: If bonds mature before 2045, refinancing at 600 bps spreads is mathematically infeasible (debt service ¿ total revenue)
- **Covenant violations**: Project finance agreements typically have rating floor covenants (maintain BBB or better); breach triggers acceleration clauses

This suggests that **preemptive action before crossing the investment grade threshold** is critical. Once rated B, recovery is impossible without extraordinary restructuring (debt forgiveness, government bailout).

5.4. Just Transition Finance Mechanisms

If Korea Power Plan dispatch reductions render Samcheok uneconomic by 2040 (10 years early), the losses are:

- **Owner (POSCO)**: $2-3 billion stranded assets (unamortized capex + negative NPV)
- **Lenders**: $2 billion debt outstanding (if no prepayment/compensation)
- **Workers**: 300+ direct jobs, 1,000+ indirect in Samcheok region
- **Local government**: Tax revenue loss, community economic disruption

Total societal cost: $4-5 billion + non-monetized social impacts. Market-driven collapse distributes losses chaotically (defaults, job losses, community shocks). Structured transition finance can allocate costs fairly:

1. **Early Retirement Contracts**: Government compensates owner for premature closure (say, 50% of stranded asset value = $1-1.5B), avoiding default cascades
2. **Transition Bonds**: Issue 10-year bonds backed by carbon auction revenues to fund compensation, worker retraining, community economic diversification
3. **Refinancing Facility**: Government guarantees below-investment-grade debt to avoid liquidity crisis, conditional on orderly phase-out agreement
4. **Just Transition Fund**: Earmark revenues from coal plant early closure savings (avoided air pollution costs, accelerated renewable deployment) for affected workers/communities

Cost-benefit analysis: $1.5B government compensation vs. $5B+ chaotic default costs suggests net savings of $3.5B from structured transition. Precedents exist (Germany's coal closure compensation, UK coal community support).

5.5. Implications for Global Coal Finance

Samcheok is representative of 1,000+ GW coal capacity under construction/planned in developing Asia. If Korea—a wealthy OECD member—faces 50-150% NPV losses on new coal, similar risks exist in:

- **Vietnam**: 13 GW coal pipeline, NDC targets incompatible with full utilization
- **Indonesia**: 22 GW coal pipeline, net-zero 2060 pledge threatens late-stage plants
- **India**: 25 GW coal pipeline, renewable cost declines eroding competitiveness

Combined capital at risk: $100+ billion. International financial institutions (IFC, ADB, multilateral development banks) financing these projects face material ESG risks. Our methodology (Korea Power Plan integration + CLIMADA physical risks + credit rating migration) is **replicable and scalable** to assess global coal stranded asset exposure.

5.6. Limitations and Future Research

Limitations:

1. Korea Power Plan extrapolation beyond 2036 assumes linear decline to net-zero; actual trajectory uncertain
2. CLIMADA hazard data at 10 km resolution; site-specific microtopography not captured
3. Model assumes no adaptation (firebreaks, flood barriers); resilience investments could mitigate physical risks
4. Static analysis; does not model dynamic dispatch optimization or real options (fuel switching, load following)

Future Research:

1. **Monte Carlo simulation**: Probabilistic Korea Power Plan scenarios + stochastic CLIMADA hazard sampling for VaR/CVaR metrics
2. **Portfolio analysis**: Extend to entire Korean coal fleet (60 units, 36 GW) for system-level stranded asset risk
3. **Real options**: Value of operational flexibility (early retirement option, fuel switching optionality) vs. committed operation
4. **Comparative analysis**: Apply framework to renewables (wind/solar) to demonstrate *negative* CRP (climate-aligned assets have lower cost of capital)

6. Conclusion

The Samcheok Blue Power plant, commissioned in 2024 as South Korea's last coal project, exemplifies the financial risks of new fossil infrastructure in a climate-constrained world. Our integrated framework—combining Korea's National Power Supply Plan, CLIMADA physical hazard data, and KIS credit rating methodology—quantifies three key findings:

1. **Policy risk dominates physical risk**: Transition scenarios reduce NPV by 251-375%, while CLIMADA climate hazards reduce NPV by 33-59%. Government energy policy—not climate change itself—is the primary driver of coal asset stranding in Korea.

2. **Investment grade loss is inevitable**: All transition scenarios (moderate, aggressive, combined) trigger credit rating downgrades from investment grade to non-investment grade, with DSCR falling from 1.81× to negative values. Once DSCR falls below 1.0×, recovery is impossible without extraordinary intervention.
3. **Climate Risk Premium is material and quantifiable**: The CRP ranges from 475 bps (moderate physical risk) to 5,854 bps (combined aggressive scenario), making projects economically unviable. Samcheok's current 6-7% bond yields suggest markets are beginning to price policy risk but remain complacent about downside scenarios.

These findings have urgent policy implications. Market forces *will* accelerate coal plant closures faster than policy mandates, but disorderly exits pose financial stability risks. Structured "Just Transition Finance" mechanisms—early retirement contracts, transition bonds, refinancing facilities—can allocate costs fairly while achieving decarbonization targets. The alternative—chaotic defaults, job losses, community disruption—is economically and socially costlier.

For investors, the message is clear: coal assets face existential risks from climate policy, physical hazards, and credit rating migration. The "Climate Risk Premium" is not theoretical; it is material, quantifiable, and accelerating. Ignoring government energy plans and spatially-explicit climate science invites massive capital destruction.

For policymakers, Samcheok demonstrates that climate commitments have financial consequences. National energy plans are not aspirational; they are legally binding constraints that destroy asset value. Recognizing stranded asset risks explicitly—and designing transition finance mechanisms proactively—is essential for orderly, just, and economically efficient decarbonization.

Acknowledgments

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