The Climate Challenge: Paris Agreement and 2 Degree C Target

Global Climate Commitments

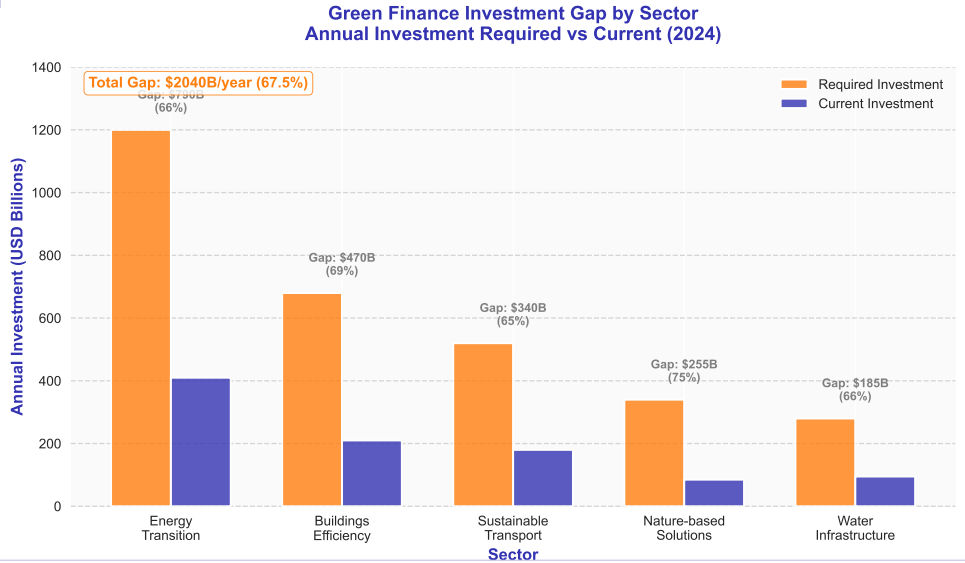
- Paris Agreement (2015): Limit warming to 1.5-2 degree C
- Net-zero targets: 140+ countries by 2050
- Carbon budget: 400 GtCO2 remaining for 1.5 degree C
- Current trajectory: 2.7 degree C warming by 2100
- Urgent action required: Emissions must halve by 2030

Finance Implications

- Energy transition investment need: $4-5 trillion annually
- Current green investment: $2 trillion annually
- Annual funding gap: $2+ trillion
- Private capital essential to close gap
- Traditional development finance insufficient

[Problem] Climate crisis creates urgent need for scaled financial solutions

The Green Finance Investment Gap: Data Puzzle



[Problem] Research question: How can capital markets mobilize $2.04T annual gap?

Market-Based Solution

- Channel private capital to environmental projects
- Use existing financial infrastructure (bond markets)
- Create specialized instruments (green bonds)
- Leverage investor ESG preferences
- Scale beyond public sector capacity

This Week's 4-Lecture Journey

- Lecture 1: WHY do green finance markets exist? (Theory)
- Lecture 2: HOW MUCH capital is mobilized? (Measurement)
- Lecture 3: HOW TO PRICE green instruments? (Valuation Part 1)
- Lecture 4: WHERE to apply and integrate? (Valuation Part 2 + Applications)

[Problem] Practical challenge: Design financial mechanisms that are profitable AND impactful

Learning Goal 1

Understand the market microstructure theory explaining why green finance markets exist and how they function

theoretical — Foundation - Establishes theoretical basis

Information Asymmetry and Signaling Theory

Core Theoretical Principles

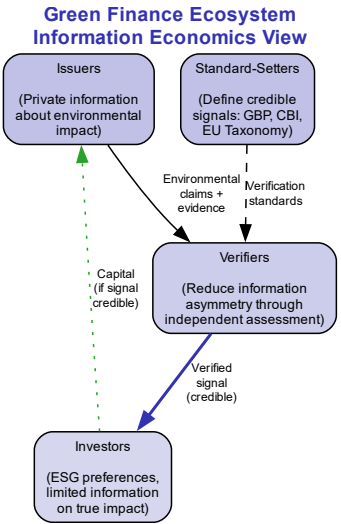
- Information asymmetry: Issuers know true environmental impact, investors cannot observe directly
- Verification as credible signaling mechanism reducing asymmetry
- Market segmentation by investor ESG preferences
- Adverse selection risk without credible signals

Market Equilibrium Predictions

- Greenium emerges from excess demand in segmented market
- Verification costs create quality differentiation
- Liquidity premium for standardized green instruments
- Reputation effects for repeat issuers

[Goal 1] Theory predicts observable phenomena - We will test these in Lecture 2

Green Finance Ecosystem: Theoretical Perspective



[Goal 1] Ecosystem structure reflects information asymmetry and signaling needs

The Information Asymmetry Problem

Why Asymmetry Exists

- Environmental impact not directly observable by investors
- Issuers possess private information about projects
- Ex-post verification costly and delayed
- Incentive for greenwashing (false green claims)
- Market failure: Good projects cannot distinguish themselves

Consequences Without Solution

- Adverse selection: Bad drives out good (lemons market)
- Risk premium demanded by rational investors
- Socially optimal green projects underfunded
- Market inefficiency and suboptimal allocation

[Goal 1] Classic asymmetric information problem from Akerlof (1970) applied to green finance

Verification as Credible Signaling

How Verification Solves Asymmetry

- Independent third-party assessment provides credible signal
- Costly signal (verification fees) separates true green from greenwashing
- Ongoing reporting creates reputation stakes for issuers
- Standards (GBP, CBI) define what constitutes credible signal

Evidence of Signaling at Work

- Over 90% of green bonds obtain external review
- Verified bonds trade at tighter spreads (greenium)
- Repeat issuers face reputation costs if greenwashing
- Market rewards standardization and transparency

[Goal 1] Signaling theory (Spence 1973) explains why verification is market standard - Empirical confirmation in Slide 38

Market Segmentation Hypothesis

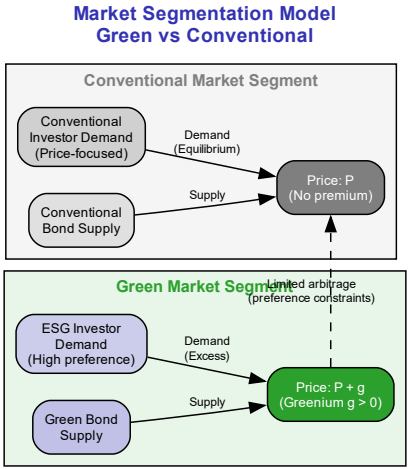
Theory of Segmentation

- Investors heterogeneous in ESG preferences (utility function)
- Dedicated ESG investors willing to accept lower returns for impact
- Conventional investors indifferent to green label
- Imperfect substitutability creates separate market segments
- Excess demand in green segment $\rightarrow$ price premium (greenium)

Testable Predictions

- Green bonds should trade at premium to identical conventional bonds
- Premium larger when ESG investor demand stronger
- Premium varies across geographies with different ESG adoption
- Limited arbitrage due to preference-based segmentation

[Goal 1] Segmentation explains persistent greenium - See yield comparison in Slide 28



[Goal 1] Separate demand curves in each segment lead to price differential (greenium)

Liquidity Benefits of Standardization

Theoretical Mechanism

- Standardized products reduce search and information costs
- Common language (GBP) facilitates comparison across issuers
- Network effects: More standardized issuance → deeper liquidity
- Liquidity premium reduces required yields

Empirical Implications

- GBP-aligned bonds should have better liquidity
- Larger green bond programs trade more actively
- Green bond indices and ETFs emerge from standardization
- First-mover advantage for standard-setters (ICMA)

[Goal 1] Standardization creates positive feedback loop improving market efficiency

Theory's Predictions for Empirical Testing

What Theory Predicts We Should Observe

- Greenium: 0-10 bps price premium for green bonds
- Verification: Majority of bonds have external review
- Standardization: Market coalesces around common principles
- Repeat issuers: Reputation effects and learning curves
- Growth: Market expands as ESG demand increases

Preview of Empirical Evidence (Lecture 2)

- Observed greenium: 0-5 bps (Theory ✓)
- External review rate: ¿90% (Theory ✓)
- Standardization increasing (Theory ✓)
- Frequent issuers dominate (Theory ✓)
- 25% CAGR 2015-2024 (Theory ✓)

[Goal 1] Strong theoretical foundation with empirical support - validated in Lecture 2 (Slides 14-24)

Learning Goal 1: Summary

Understand market microstructure theory explaining green finance

What We Achieved

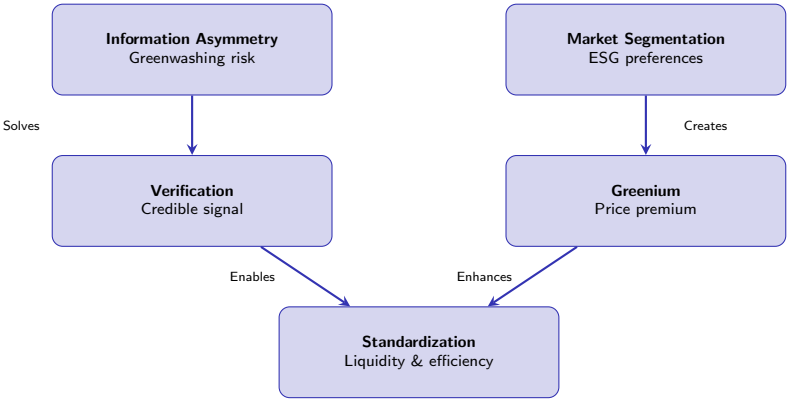
- ✓ Identified information asymmetry as core problem requiring verification
- ✓ Analyzed how signaling theory explains verification as market standard
- ✓ Understood market segmentation hypothesis for greenium existence
- ✓ Connected standardization to liquidity and efficiency gains

Can You Now...

- Explain why greenium exists using economic theory?
- Describe how verification solves information asymmetry?
- Predict which factors increase or decrease greenium?
- Apply this framework to analyze new green instruments?

[Goal 1] Achieved - Theoretical foundation complete. Next: Quantitative measurement

Concept Map: Theoretical Foundations



[Goal 1] Complete theoretical framework showing interconnected concepts

Learning Goal 2

Quantify and analyze global green finance market size, growth trajectories, and geographic distribution

quantitative — Build - Develops empirical measurement capabilities

Measuring the Green Finance Market

Methodological Challenges

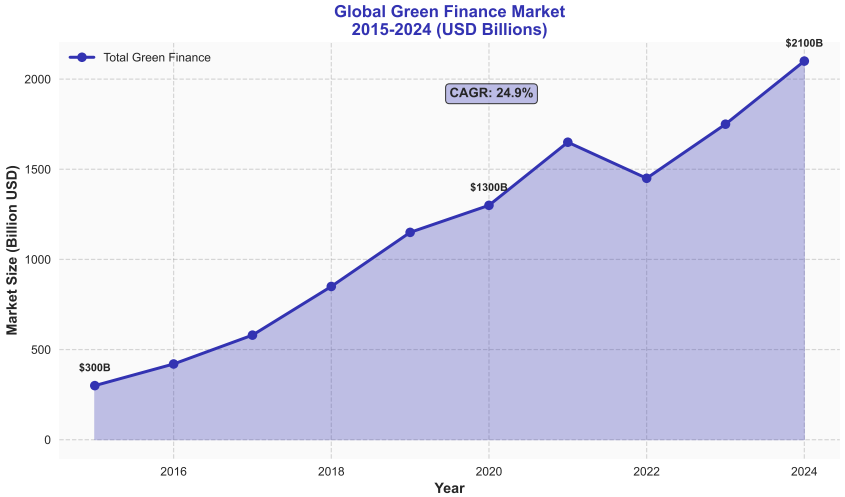
- Definition: What qualifies as "green"? (Taxonomy dependence)
- Double counting: Issuance vs outstanding amounts
- Currency: Conversion to common denominator (USD)
- Coverage: Data availability varies by region and instrument

Standard Metrics

- Total market size: Outstanding amount (stock)
- Annual issuance: New volume each year (flow)
- CAGR: Compound Annual Growth Rate
- Market share: By instrument, region, sector

[Goal 2] Rigorous quantification requires clear methodology and consistent definitions

Global Green Finance Market Growth 2015-2024



[Goal 2] Market grew from $300B (2015) to $2.1T (2024) - This validates the growth prediction from Slide 11

Growth Rate Analysis: CAGR Calculation

CAGR Formula and Application

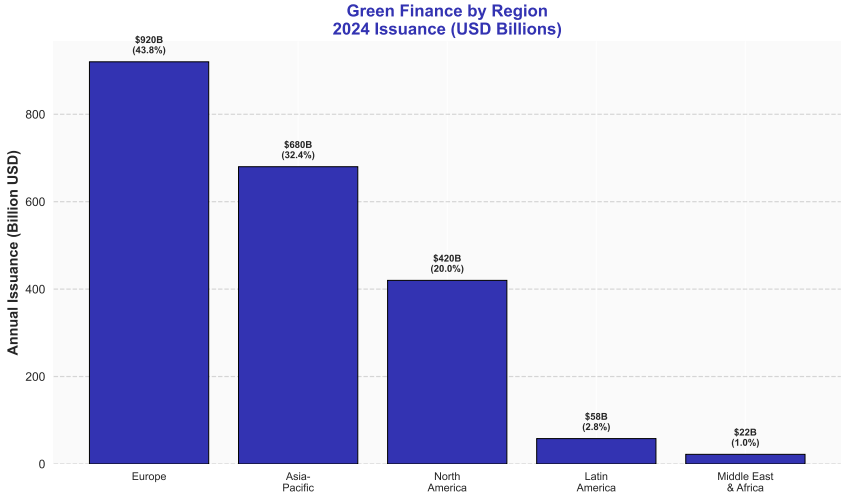
- Formula: $CAGR = (V_{final}/V_{initial})^{1/n} - 1$
- Period: 2015-2024 (n = 9 years)
- Initial: \$300B (2015)
- Final: \$2,100B (2024)
- Calculation: $(2100/300)^{1/9} - 1 = 24.9\%$

Interpretation and Context

- 24.9% CAGR indicates explosive growth phase
- Comparison: Global bond market ∼5% CAGR same period
- Green finance growing 5× faster than conventional
- 2022 dip (\$1.45T) due to broader market volatility

[Goal 2] Quantitative analysis confirms theoretical prediction of rapid market expansion

Geographic Distribution of Green Finance



[Goal 2] Europe 44%, Asia-Pacific 32%, Americas 20% - Reflects regulatory push predicted in theory (Slide 10)

Regional Patterns and Drivers

Europe: Market Leader

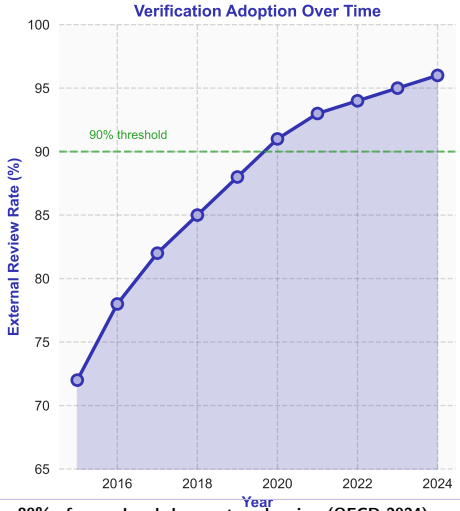
- 44% global market share ($920B annual issuance)
- Driver: EU Taxonomy mandatory disclosure
- SFDR regulation creates demand from asset managers
- Strong sovereign issuance (France, Germany, UK)

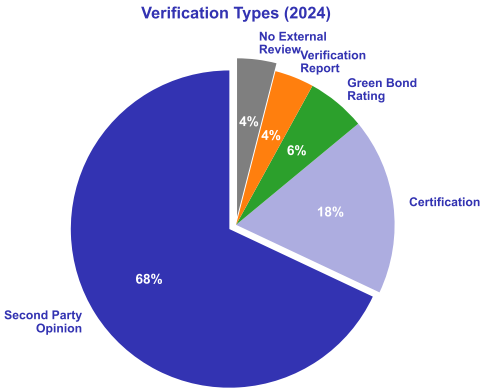
Asia-Pacific: Rapid Growth

- 32% market share ($680B), fastest growth region
- China dominates ($450B), policy-driven expansion
- Japan, South Korea increasing (net-zero commitments)
- Southeast Asia emerging (ASEAN Taxonomy)

[Goal 2] Regional variation driven by policy frameworks and regulatory mandates

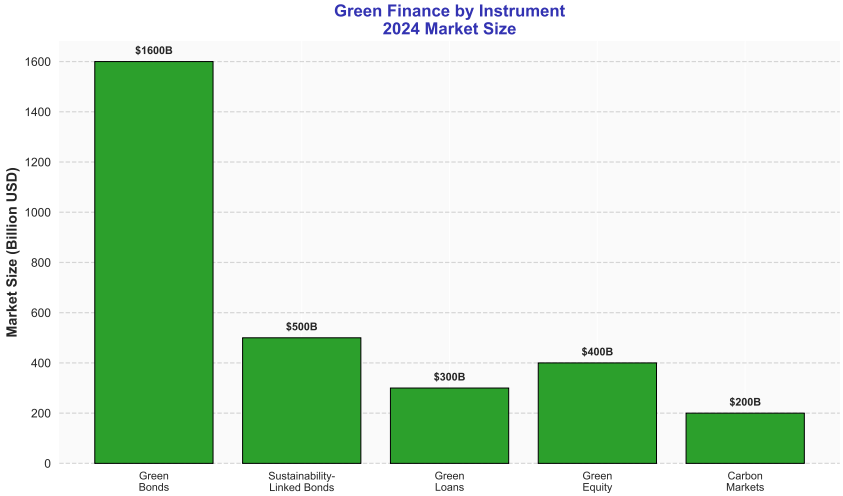
External Verification in Green Bond Market
Evidence of Signaling Theory





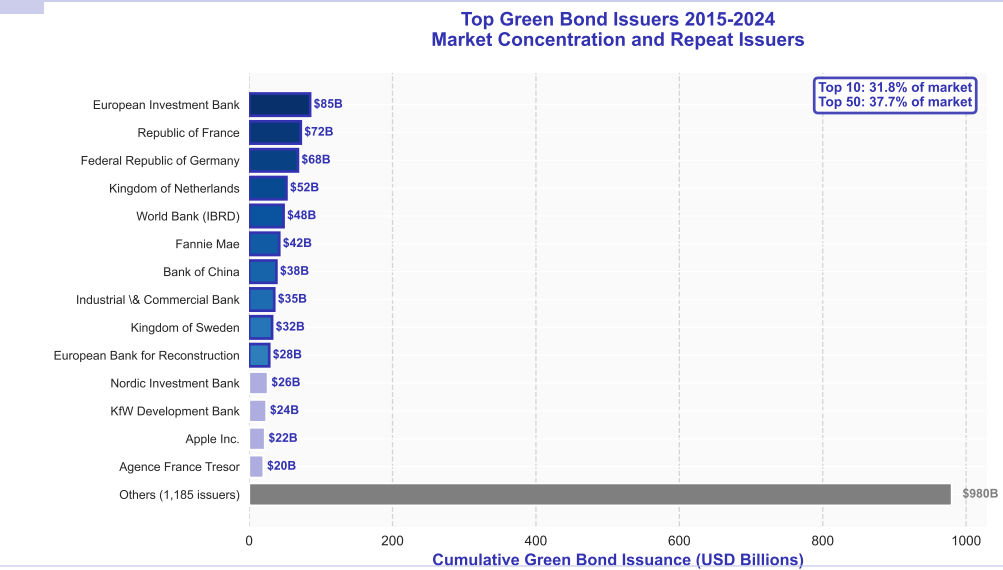
[Goal 2] Over 80% of green bonds have external review (OECD 2024) - validates signaling theory from Lecture 1

Market Composition by Instrument Type



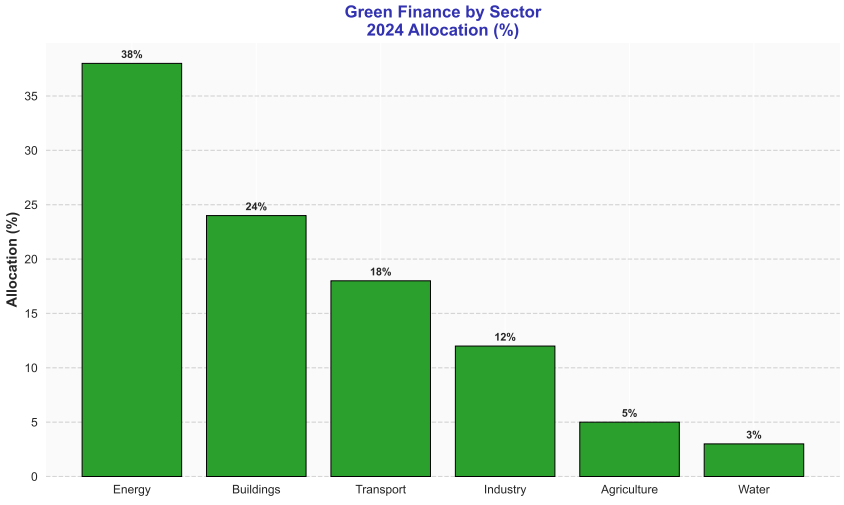
[Goal 2] Green bonds $1.6T (76%), Sustainability-linked bonds $500B (24%) of total

Top Green Bond Issuers 2015-2024



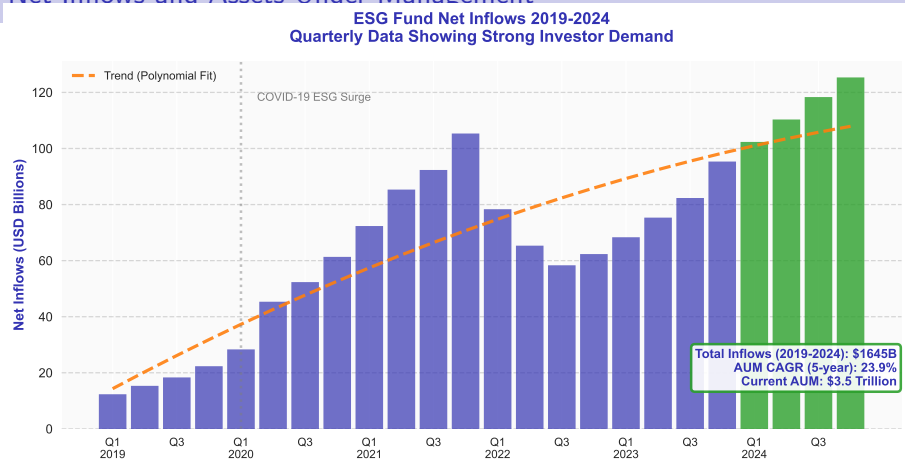
[Goal 2] Repeat issuers dominate market - confirms reputation effects predicted in theory

Allocation Across Economic Sectors



[Goal 2] Energy 38%, Buildings 24%, Transport 18% - aligns with decarbonization priorities

ESG Fund Net Inflows and Assets Under Management



Quantitative Summary: Key Statistics

Market Size Metrics (2024)

- Total outstanding: $2.1 trillion
- Annual issuance: $650 billion
- Green bonds outstanding: $1.6T (76%)
- Number of issuers: 1,200+ globally
- Average deal size: $540 million

Growth and Distribution

- 9-year CAGR: 24.9% (2015-2024)
- Regional: EU 44%, APAC 32%, Americas 20%
- Sectoral: Energy 38%, Buildings 24%, Transport 18%
- Forecasted 2030: $5.0-6.0 trillion

[Goal 2] Comprehensive quantitative picture validates theoretical predictions from Lecture 1

Learning Goal 2: Summary

Quantify and analyze market size, growth, and distribution

What We Achieved

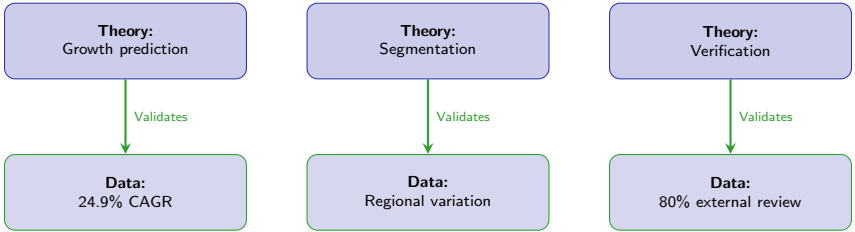
- ✓ Quantified market at $2.1T with 24.9% CAGR (2015-2024)
- ✓ Analyzed regional distribution: Europe leads (44%), Asia growing fastest
- ✓ Measured instrument composition: Green bonds dominant (76%)
- ✓ Validated theoretical predictions with empirical data

Can You Now...

- Calculate growth rates (CAGR) for market segments?
- Compare regional adoption and explain differences?
- Analyze sector allocation and investment priorities?
- Use empirical data to test theoretical hypotheses?

[Goal 2] Achieved - Quantitative measurement complete. Next: Mathematical valuation models

Concept Map: Theory + Evidence Integration



[Goal 2] Theory validated by data - Strong empirical foundation for valuation models

Learning Goal 3

Derive and apply bond pricing models incorporating greenium and environmental premium adjustments

mathematical — Apply - Demonstrates mathematical valuation methods

Classical Bond Pricing: Derivation from First Principles

Starting Point

$$P_0 = \sum_{t=1}^{T} \frac{C}{(1+r)^t} + \frac{F}{(1+r)^T}$$

Assumptions:

- Constant discount rate r (risk-free + credit spread)
- Fixed annual coupon C
- Face value F repaid at maturity T
- No embedded options or default

Algebraic Simplification

1. Separate coupon annuity from principal:

$$P_0 = C \sum_{t=1}^{T} (1+r)^{-t} + F(1+r)^{-T}$$

2. Apply geometric series formula to annuity:

$$= C \cdot \frac{1-(1+r)^{-T}}{r} + F(1+r)^{-T}$$

3. Standard decomposition for analysis:

$$= PV(\text{Coupons}) + PV(\text{Principal})$$

[Goal 3] Classical formula forms mathematical foundation for all bond valuation

Theoretical Extension

$$P_G = \sum_{t=1}^{T} \frac{C}{(1+r-g)^t} + \frac{F}{(1+r-g)^T}$$

Key Elements:

- Greenium $g > 0$ (0-5 bps typically)
- Same cash flows as conventional bond
- Environmental premium priced via lower required return
- Adjust discount rate by greenium g

Price Differential Analysis

1. Green bond trades at premium:

$$P_G > P_0 \text{ if } g > 0$$

2. Convert decimal to basis points:

$$\text{Greenium (bps)} = g \times 10000$$

3. Price difference approximation using duration D:

$$P_G - P_0 \approx C \cdot g \cdot D$$

[Goal 3] Mathematical model quantifies greenium's impact on bond valuation

Numerical Example: Green vs Conventional Pricing

Bond Specifications

- Face value: $F = 1000$ (EUR)
- Coupon rate: 3% annual (C = 30 EUR)
- Maturity: T = 10 years
- Risk-free rate: 2%
- Credit spread: 0.5%
- Greenium: g = 0.03% (3 bps)

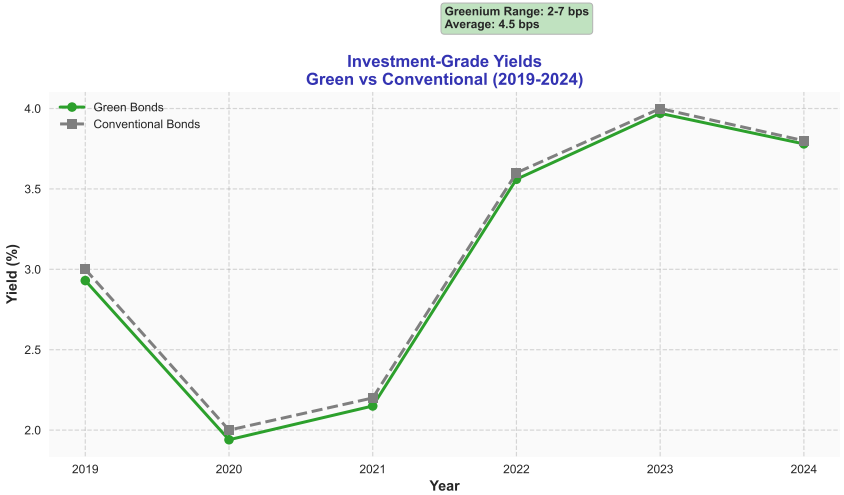
Valuation Calculations

- Conventional: $r = 2.5\%$
- Price: $P_0 = 1043.76$ EUR
- Green: $r_G = 2.47\%$ (2.5% - 0.03%)
- Price: $P_G = 1046.89$ EUR
- Difference: 3.13 EUR (0.3% premium)

Try it yourself: Calculate price for greenium = 5 bps
Answer: $P_G = 1048.98$ *EUR (5.22 EUR premium)*

[Goal 3] 3 bps greenium translates to €3.13 price premium on €1000 bond

Yield Curves: Green vs Conventional Bonds



[Goal 3] Greenium of 3-4 bps confirms segmentation theory (Slide 8) - Empirical validation of theory

Duration Analysis and Price Sensitivity

Modified Duration

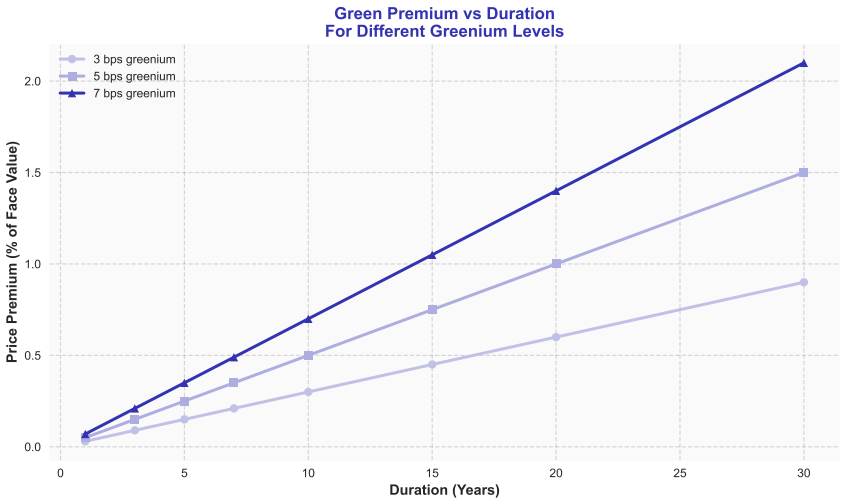
- Duration $D = \frac{1}{P} \frac{\partial P}{\partial r}$
- Measures price sensitivity to yield changes
- Higher duration $\rightarrow$ greater greenium impact
- 10-year bond: $D \approx 8.5$ years

Greenium Sensitivity

- Price change: $\Delta P \approx -P \cdot D \cdot \Delta r$
- 1 bp greenium on 10-yr bond: 0.085% price impact
- Longer maturity amplifies greenium effect
- Investor arbitrage limited by segmentation

[Goal 3] Mathematical relationship validates pricing framework - Duration increases greenium impact

Pricing Model: Green Premium vs Duration



[Goal 3] Longer duration bonds show larger absolute price premium for given greenium

Risk-Return Analysis for Green Bonds

Return Components

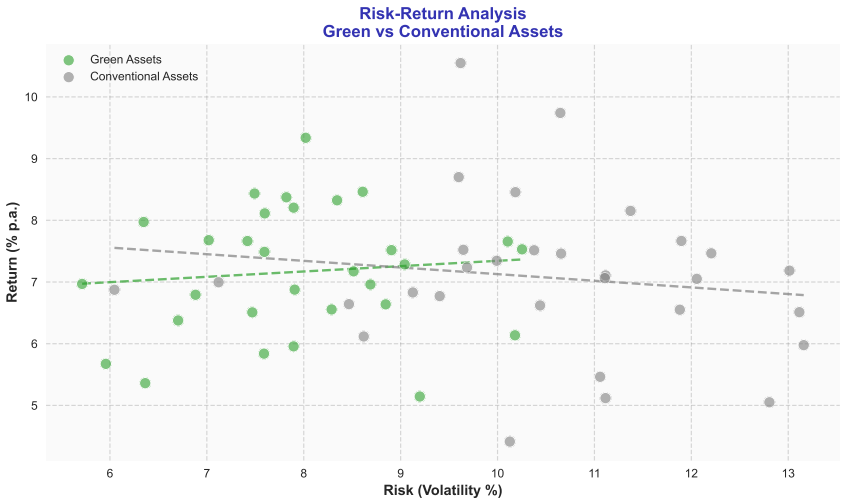
- Base return: Risk-free rate + credit spread
- Greenium effect: Lower required return (-3 to -5 bps)
- Liquidity premium: May offset greenium (varies)
- Total return: Comparable to conventional bonds

Risk Profile

- Credit risk: Identical to conventional bonds (same issuer)
- Interest rate risk: Measured by duration (same as conventional)
- Greenwashing risk: Specific to green bonds (mitigated by verification)
- Regulatory risk: EU Taxonomy changes, standards evolution

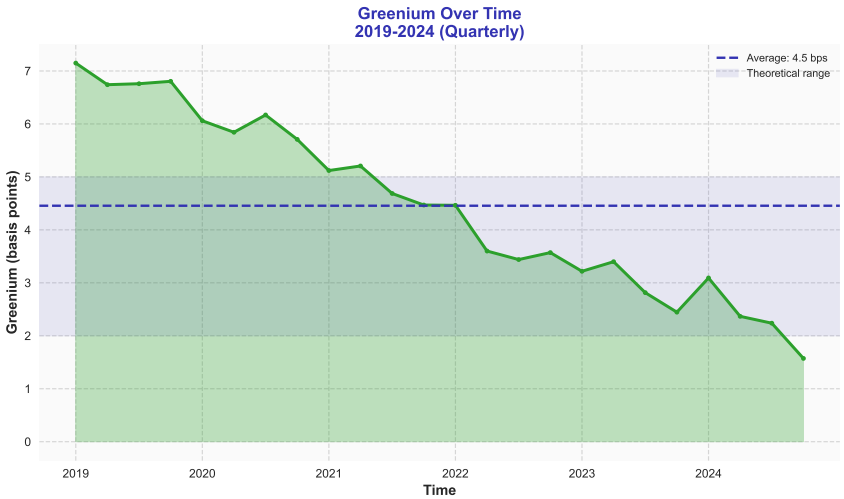
[Goal 3] Green bonds offer similar risk-return profile with additional ESG benefit

Risk-Return Profile: Green vs Conventional



[Goal 3] Empirical evidence: Competitive risk-adjusted returns with lower volatility

Greenium Evolution 2019-2024



[Goal 3] Greenium declining from 7 bps (2019) to 2 bps (2024) as supply meets demand

Week 1 Integration: Complete Green Finance Foundation

Three-Goal Narrative Complete

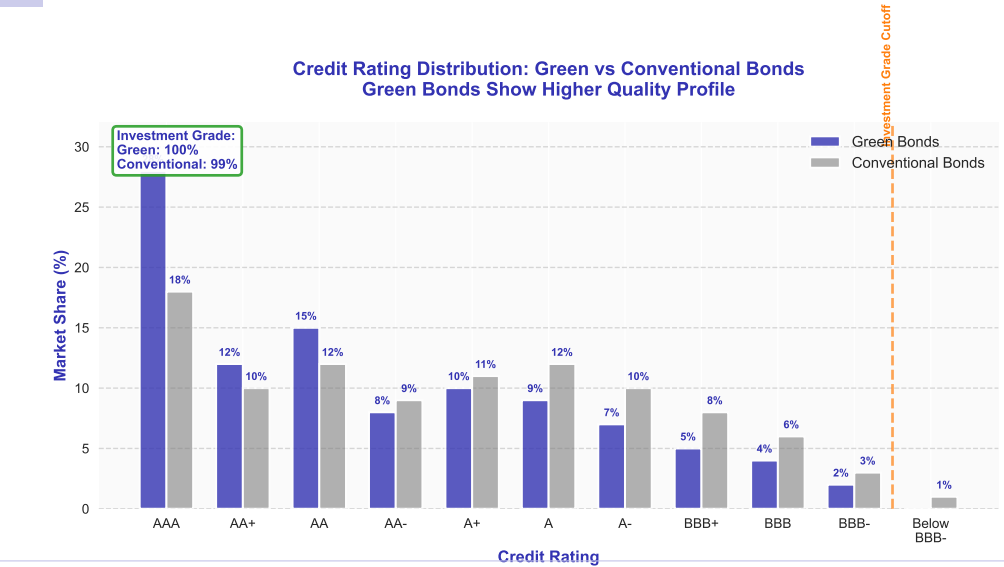
- ✓ Goal 1 (Theory): WHY green finance exists - information asymmetry, segmentation
- ✓ Goal 2 (Measurement): HOW MUCH - $2.1T market, 25% CAGR, geographic distribution
- ✓ Goal 3 (Valuation): HOW TO PRICE - pricing models, greenium quantification
- ✓ Story arc: Theoretical foundation → Empirical evidence → Mathematical application

Week 1 Mastery: Can You...

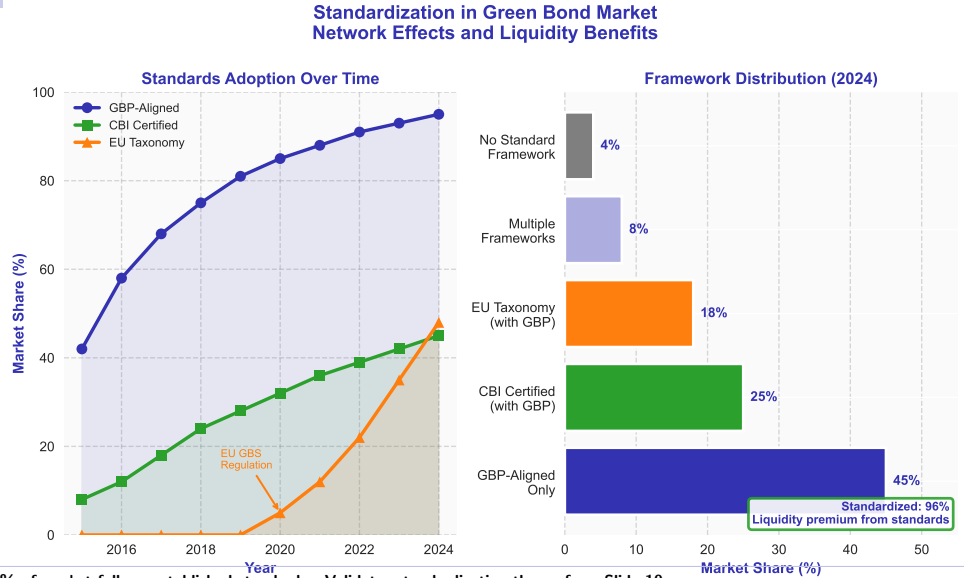
- Explain greenium using microstructure theory?
- Calculate market growth rates and project future size?
- Derive bond pricing models and apply to green bonds?
- Integrate theory, data, and mathematics in analysis?

Week 1 foundations complete - Integrated theoretical, empirical, and mathematical frameworks

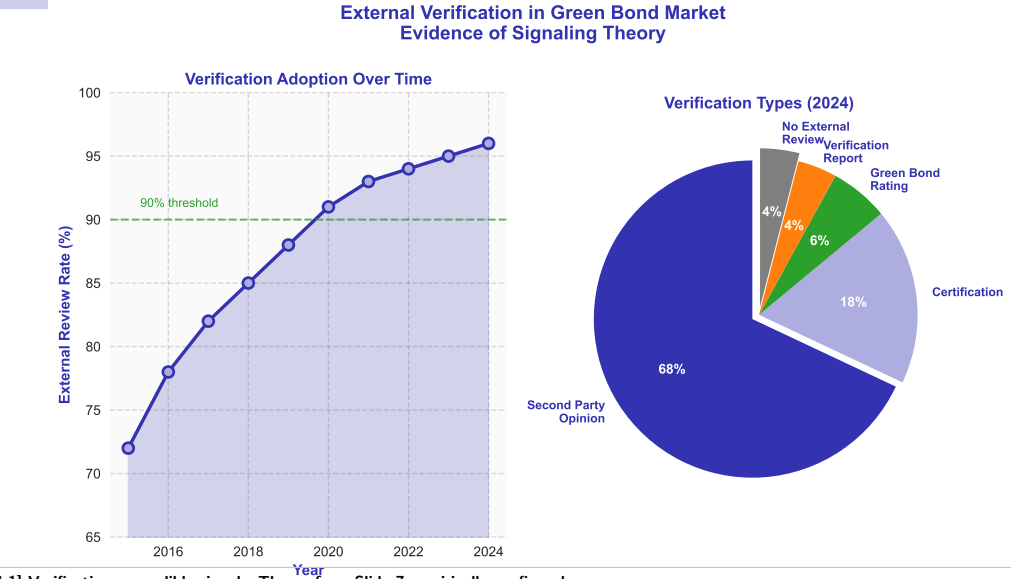
Credit Rating Distribution: Green vs Conventional



[Goal 3] Green bonds show higher credit quality (predominantly investment grade) - Lower credit risk

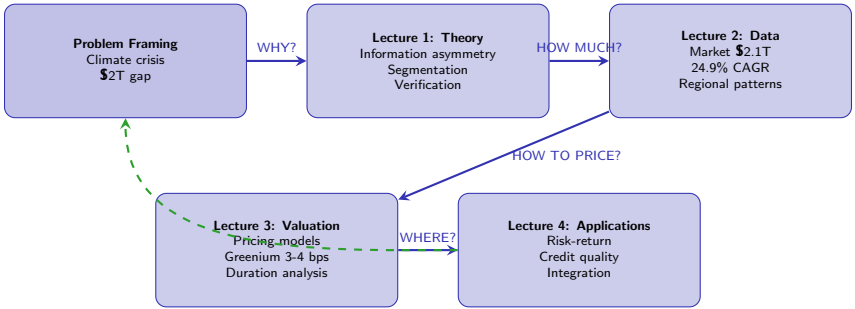


[Goal 1] 96% of market follows established standards - Validates standardization theory from Slide 10



[Goal 1] Verification as credible signal - Theory from Slide 7 empirically confirmed

Complete Integration: All 4 Lectures Connected



[All Goals] Complete journey from problem to application - Theory-Evidence-Mathematics integrated

Interactive Risk-Return Positioning

Investment Options

1. German green sovereign (10-yr, AAA, 3 bps greenium)
2. France green corporate (5-yr, A, 4 bps greenium)
3. China green development (7-yr, BBB+, 5 bps greenium)
4. US sustainability-linked (10-yr, AA, 2 bps greenium)

Your Constraints

- Target duration: 7-8 years
- Risk appetite: Investment grade only
- ESG preference: High greenium preferred

Decision Framework

- Apply Goal 3 pricing models
- Consider Goal 1 theoretical predictions
- Use Goal 2 market data for context
- Evaluate credit risk vs greenium trade-off

Recommended: China green development
Rationale: Optimal duration (7 yrs), investment grade, highest greenium (5 bps), growing market

[Application] Integrate all three goals to make informed investment decisions

Real-World Application: France's Green Sovereign Bond

Transaction Details (2017-2024)

- First sovereign green bond: January 2017
- Total issuance: $85 billion (2017-2024)
- Maturity range: 10-25 years
- Average greenium: 3-5 bps at issuance
- Use of proceeds: Energy transition, sustainable transport

Market Impact

- Oversubscribed 7× on average
- Attracted new ESG-dedicated investors
- Set benchmark for sovereign green issuance

How Theory Explains Success

- **Goal 1:** AAA rating + verification = credible signal reducing information asymmetry
- **Goal 2:** Large issue size ($7B+) = liquidity premium + standardization benefits
- **Goal 3:** Greenium 3-5 bps = competitive pricing attracting ESG-segmented investors

Outcomes

- Successful funding: $85B mobilized for climate
- Market leadership: France top sovereign issuer
- Demonstrated scalability of green finance

[Application] France case integrates all theoretical, empirical, and valuation concepts from Week 1

Looking Ahead: Week 2 Preview

What We Accomplished in Week 1

- Built theoretical foundation (microstructure theory)
- Quantified global market ($2.1T, 25% CAGR)
- Derived mathematical pricing models
- Applied framework to real investments

Open Questions for Week 2

- How are green bonds actually structured?
- What is the issuance process step-by-step?
- How do taxonomies define "green"?
- What role do third-party verifiers play?

Week 2 Focus: Green Bond Structures

- Issuance lifecycle and documentation
- Green Bond Principles (ICMA framework)
- Taxonomy alignment (EU, China, ASEAN)
- Verification and certification processes
- Impact reporting requirements

Building on Week 1

- Week 1: WHY and HOW MUCH (macro view)
- Week 2: WHAT and HOW (micro implementation)
- Integration: Theory $\rightarrow$ Practice

Week 2 deepens understanding by examining operational details of green bond issuance and standards