
Sustainable Finance and the Reallocation of Capital for Ecological Transition

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Abstract

This paper examines the role of sustainable finance in supporting green investment and financing the ecological transition. It reviews three interconnected dimensions: the integration of environmental, social and governance criteria into investment decisions and asset pricing; the development of green financial instruments and financial intermediation; and the financing mechanisms supporting renewable energy, public green investment and corporate transition. The literature indicates that sustainability considerations increasingly affect investor behavior, capital allocation, risk assessment and financing costs, although their financial consequences remain heterogeneous across markets and institutional settings. ESG information can redirect investment flows, but disagreements among rating providers and differences in materiality limit the reliability of sustainability signals. Green bonds, green credit and sustainable banking mechanisms can facilitate environmental investment, yet their effectiveness depends on certification, disclosure quality, liquidity, policy credibility and borrower characteristics. Public financial institutions also play an important role in absorbing early-stage risks, creating markets and mobilizing private capital for low-carbon technologies. The reviewed evidence further shows that climate transition requires more than specialized green instruments. Financial-system structure, corporate investment decisions, regulatory frameworks and coordinated public policies influence whether capital is effectively redirected toward environmentally sustainable activities. Sustainable finance therefore represents an evolving institutional framework through which environmental objectives, financial risk and long-term investment are progressively integrated.

Keywords: Sustainable finance; Green investment; Climate finance; Green bonds; Ecological transition

JEL classification: G11; G21; G23; Q42; Q54

Introduction

The ecological transition requires substantial and persistent changes in the allocation of financial resources across sectors, technologies and firms. Sustainable finance has consequently developed from a relatively specialized investment approach into a broader framework through which environmental considerations are incorporated into portfolio management, corporate financing and financial regulation. The literature shows that this evolution operates through several mechanisms. ESG information influences investor decisions and fund flows, while the ma-



teriality of environmental and social indicators determines whether such information is financially informative. Sustainability can also affect corporate resilience and investor preferences, thereby modifying the relationship between financial performance and non-financial objectives. At the same time, climate-related risks are becoming increasingly incorporated into asset prices, lending conditions and institutional investment strategies. Carbon exposure, physical climate risks and uncertainty surrounding environmental policies can influence expected returns, borrowing costs and hedging demand. These developments suggest that sustainable finance cannot be understood solely as an ethical investment category. It increasingly forms part of conventional financial decision-making because environmental conditions may affect firms' expected cash flows, risk profiles and long-term competitiveness. The financing of ecological transition therefore depends on how financial markets identify, measure and price environmental information and subsequently translate these assessments into capital-allocation decisions.

This transformation is also reflected in the rapid development of dedicated financial instruments and institutional mechanisms for environmental investment. Green bonds have become an important mechanism for financing environmentally oriented projects, while certification, external verification and issuer credibility determine whether they provide measurable financing advantages. Green banking and climate-related prudential policies extend sustainable finance beyond capital markets by incorporating environmental considerations into credit assessment, financial supervision and central-bank activities. However, financing the ecological transition also requires addressing the specific characteristics of renewable-energy and low-carbon investments. High initial capital requirements, technological uncertainty, long investment horizons and policy dependence can prevent private investors from financing projects even when their long-term social benefits are substantial. Public investment banks, guarantees, direct public investment and other forms of risk sharing can therefore complement private finance by reducing uncertainty and creating investable markets. The literature further indicates that financial constraints are particularly significant in emerging and developing economies, where higher costs of capital and weaker institutional capacity can slow green investment. These considerations justify examining sustainable finance as an interconnected system involving investors, firms, commercial banks, central banks and public financial institutions rather than as a collection of isolated environmental instruments.

1. Sustainable Finance, ESG and the Pricing of Environmental Risk

1.1. ESG Integration, Socially Responsible Investment and Financial Performance

Hartzmark and Sussman (2019) show that sustainability information can directly influence investor behavior when it is presented through accessible and standardized signals. The inflows toward highly rated funds and withdrawals from poorly rated funds imply that ESG classifications can redirect capital even when the underlying financial characteristics of portfolios remain unchanged. This mechanism complements Khan et al. (2016), who demonstrate that the financial relevance of sustainability depends on identifying material rather than immaterial environmental and social issues. Their findings imply that investors should not treat ESG information as a uniform collection of indicators but should concentrate on dimensions capable of affecting competitive position and future cash flows. Friede et al. (2015) reinforce this interpretation by showing, across more than 2,000 studies, that the relationship between ESG performance and corporate financial performance is predominantly non-negative and more frequently positive than negative. This evidence implies that sustainability integration does not necessarily require sacrificing financial returns. Revelli and Viviani (2015), however, introduce an important qualification by showing that socially responsible investment does not systematically outperform or

underperform conventional investment once methodological and portfolio characteristics are considered. Taken together, these contributions imply that sustainable investment is better understood through the quality, materiality and interpretation of ESG information than through a simple assumption of automatic financial superiority.

Lins et al. (2017) extend the financial implications of sustainability by showing that corporate social responsibility can operate as an intangible form of social capital, particularly during periods of declining trust. The comparatively stronger stock returns, profitability and growth of firms with higher pre-crisis CSR characteristics imply that responsible corporate practices may strengthen resilience when confidence in companies and institutions deteriorates. Busch et al. (2016) broaden this perspective by arguing that sustainable finance should not be restricted to determining whether environmental and social practices improve corporate financial outcomes. Their distinction between instrumental and broader sustainability approaches implies that financial markets also influence the direction of economic development through their capital-allocation decisions. Riedl and Smeets (2017) provide a complementary demand-side mechanism by demonstrating that investors may derive utility from aligning portfolios with their social preferences and may therefore accept different financial characteristics when selecting socially responsible funds. This implies that capital allocation can be shaped by non-financial preferences independently of expected returns. El Ghouli and Karoui (2017) further show that corporate social responsibility characteristics can influence mutual-fund performance and investor flows, although these effects depend on investment-strategy characteristics. Together, these contributions imply that sustainable finance emerges from interactions among corporate responsibility, investor preferences, asset-management decisions and the broader role of financial markets in directing resources toward different economic activities.

Ammann et al. (2019) demonstrate that ESG ratings can become part of the institutional infrastructure through which sustainability considerations affect financial decisions. Their evidence that highly rated mutual funds receive additional investment while poorly rated funds experience withdrawals implies that ratings reduce the information-processing burden associated with multidimensional sustainability information and make ESG characteristics more operational for portfolio selection. This institutional mechanism is consistent with Hartzmark and Sussman (2019), who similarly show that easily accessible sustainability ratings can redirect investment flows without corresponding changes in the financial characteristics of the underlying funds. However, the implications of such rating-based allocation should be considered alongside Khan et al. (2016), whose distinction between material and immaterial sustainability dimensions suggests that not every ESG signal carries the same financial relevance. Ratings may therefore facilitate investment decisions, but their economic significance depends partly on whether they capture sustainability issues connected to firms' competitive position and future cash flows. Busch et al. (2016) add a broader implication by emphasizing that sustainable finance concerns not only the financial consequences of sustainability for investors but also the capacity of financial markets to influence sustainable economic development. Taken together, these contributions imply that ESG ratings and classifications can shape capital allocation, while their broader contribution depends on the informational content they convey and the direction in which financial resources are ultimately redirected.

1.2. Sustainable Asset Pricing, ESG Ratings and Green Returns

Berg et al. (2022) show that the effectiveness of sustainable investment depends partly on the reliability of the information through which firms are evaluated. Their finding that ESG ratings diverge substantially because of differences in scope, measurement and weighting implies that investors may face difficulties in identifying firms with consistently superior sustainability char-

acteristics. This implication is reinforced by Avramov et al. (2022), who demonstrate that uncertainty and disagreement surrounding ESG assessments can alter optimal portfolio allocations and reduce the expected benefits of sustainability integration. When ESG information becomes less reliable, investors may reduce their sustainability tilts or require compensation for ambiguity. Gibson Brandon et al. (2021) provide related evidence by showing that greater disagreement among ESG rating providers is associated with higher stock returns, particularly when disagreement concerns environmental dimensions. This relationship implies that investors can treat ESG uncertainty as a form of risk or information asymmetry affecting required returns and financing costs. Pedersen et al. (2021) complement these findings through the ESG-efficient frontier, where sustainable portfolio choices depend simultaneously on ESG preferences and the informational content of sustainability scores. Together, these contributions imply that sustainable asset management cannot depend solely on the availability of ESG indicators; it also requires credible, comparable and sufficiently informative measures capable of supporting portfolio decisions without introducing excessive uncertainty.

Bolton and Kacperczyk (2021) demonstrate that carbon emissions constitute a financially relevant corporate characteristic by documenting higher subsequent stock returns among firms with greater levels and growth rates of emissions. The resulting carbon premium implies that investors may require compensation for carbon-transition exposure or that environmentally oriented exclusions can affect the pricing of high-emission companies. Pástor et al. (2021) provide a theoretical explanation for this type of pricing mechanism by showing that environmentally concerned investors may accept lower expected returns on greener assets because they derive utility from holding them. Their framework also implies that unexpected increases in environmental concern can generate superior realized green returns despite lower expected returns. Pástor et al. (2022) empirically reinforce this distinction by showing that the strong realized performance of green stocks can largely reflect increases in climate concerns rather than permanently superior expected returns. This shift in demand can raise green asset prices while lowering the future cost of capital of environmentally responsible firms. Engle et al. (2020) add a risk-management dimension by demonstrating that portfolios can be constructed to hedge innovations in climate-change news. Their contribution implies that climate exposure can enter conventional portfolio management as a source of financial risk. Together, these studies connect emissions, environmental preferences, realized returns and hedging strategies within a common mechanism linking climate transition to asset prices and corporate financing conditions.

Choi et al. (2020) show that climate-related investment behavior is not driven exclusively by long-term economic fundamentals because abnormal temperature experiences can increase public attention to global warming and influence trading in climate-related stocks. Their findings imply that the salience of environmental conditions can affect market valuation through behavioral channels, producing changes in investor demand that may occur independently of new information about firms' underlying cash flows. This mechanism can be linked to Pástor et al. (2022), who show that increasing concern about climate change can contribute to the superior realized performance of green assets while simultaneously reducing their prospective returns as demand raises current prices. Pedersen et al. (2021) place such investor preferences within a portfolio-choice framework by demonstrating that optimal sustainable portfolios differ according to whether investors ignore ESG information, use it for return prediction or directly value sustainability characteristics. The implication is that identical sustainability information can produce different allocation decisions depending on investor objectives. Bolton and Kacperczyk (2021) further show that markets price carbon exposure through a return premium associated with higher emissions. Considered together, these contributions imply that sustainable asset prices are shaped by interactions among climate salience, investor preferences, portfolio

objectives and corporate carbon exposure, rather than by a single uniform relationship between environmental performance and financial returns.

1.3. Carbon Risk, Physical Climate Risk and the Cost of Capital

Javadi and Masum (2021) show that climate exposure can directly affect corporate borrowing conditions, as firms facing greater climate risk tend to incur higher bank-loan costs. The stronger effect among environmentally aware lenders implies that the banking sector can transmit climate considerations to firms through credit pricing. Jung et al. (2018) reach a related conclusion by showing that carbon risk influences debt financing, especially when corporate management displays limited awareness of this exposure. Their findings imply that lenders do not assess carbon intensity independently of managerial responses, since credible carbon-risk management can moderate some of the financial consequences associated with environmental exposure. Krueger et al. (2020) broaden this mechanism by documenting that institutional investors increasingly regard climate change as financially relevant and incorporate regulatory and other climate risks into investment processes. Their growing engagement with portfolio companies implies that financial institutions can affect corporate behavior before climate risks fully materialize in financial statements. Hong et al. (2019), however, show that physical climate risks such as drought have historically been underpriced in stock markets, although pricing improves as awareness develops. Considered together, these contributions imply that improved recognition of climate risk by banks and institutional investors can progressively alter both debt and equity financing conditions, thereby redirecting capital toward firms better prepared for physical and transition-related environmental pressures.

Ilhan et al. (2021) demonstrate that climate-transition exposure affects not only expected returns but also the pricing of extreme downside risk. Their evidence that carbon-intensive firms face more expensive option protection, particularly when climate-policy uncertainty increases, implies that investors assign financial value to the possibility of abrupt regulatory tightening. Bolton and Kacperczyk (2023) complement this result internationally by documenting a global carbon premium in equity markets, although its magnitude differs across countries and institutional environments. Their findings imply that transition risk is increasingly reflected in corporate costs of equity beyond individual national markets. Hsu et al. (2023) extend this pricing mechanism beyond carbon emissions by identifying a pollution premium among firms with greater toxic-emission intensity. The stronger effect when environmental attention rises implies that the pricing of environmental externalities depends partly on investors' perceptions of future regulatory and reputational costs. Baldauf et al. (2020) introduce an additional dimension by showing that even objectively similar physical climate exposure can produce different asset valuations when market participants hold different beliefs about climate change. Together, these studies imply that environmental risk premiums depend on both measurable exposure and the way investors interpret future policy, environmental damage and regulatory consequences, producing heterogeneous financing effects across firms, markets and asset classes.

Alok et al. (2020) show that direct experience with climatic disasters can alter professional investment decisions, as mutual-fund managers exposed to severe weather subsequently reduce holdings in firms located in disaster-prone areas even when changes in fundamentals do not fully explain their behavior. This implies that physical climate events can influence capital allocation through experience-based reassessment as well as conventional risk evaluation. Baldauf et al. (2020) identify a comparable role for beliefs in real-estate markets, where properties facing similar sea-level-rise exposure receive different valuations according to local attitudes toward climate change. Their findings imply that identical objective environmental risks may generate unequal financing consequences when investors interpret those risks differently. Krueger

et al. (2020) provide an institutional counterpart by showing that many professional investors already incorporate climate considerations into investment processes and increasingly engage firms on climate-related issues. This growing attention can strengthen the market consequences of unmanaged environmental exposure. Ilhan et al. (2021) further demonstrate that carbon-intensive companies face higher costs of protection against severe downside outcomes when climate-policy uncertainty rises. Taken together, these contributions imply that climate-related financing conditions emerge from an interaction between objective exposure, investor experience, beliefs and institutional risk management, meaning that environmental shocks can affect valuation even before their full economic consequences become observable.

2. Green Financial Instruments and Financial Intermediation

2.1. Green Bonds: Pricing, Certification and Issuer Effects

Flammer (2021) shows that corporate green-bond issuance can generate benefits that extend beyond debt financing itself, since issuance is followed by positive stock-market reactions, improvements in environmental performance and shifts toward longer-term and environmentally oriented investors. The stronger effects observed for externally certified bonds imply that credibility influences whether green financing produces both market and environmental consequences. Hyun et al. (2020) reinforce this implication by showing that certification and adherence to recognized standards are associated with a stronger pricing premium. Their findings suggest that investors distinguish among green securities according to the verifiability of environmental commitments rather than relying on the label alone. Bachelet et al. (2019) similarly show that issuer characteristics and third-party verification help explain heterogeneous green-bond pricing, with more credible and externally verified issues tending to obtain stronger financial advantages. This indicates that certification can reduce information asymmetry and make environmental claims more financially relevant. Zerbib (2019) complements these findings by identifying a modest negative yield premium for green bonds relative to comparable conventional securities. The implication is that environmentally oriented demand can lower financing costs, but the size of this benefit depends on issuer and bond characteristics. Together, these contributions indicate that the financing advantage of green bonds is closely linked to credibility, certification and investor confidence in the environmental quality of the funded projects. Tang and Zhang (2020) demonstrate that green-bond issuance can influence corporate finance through several channels beyond the direct cost of debt. Their evidence of positive stock-market reactions, changes in institutional ownership and improved stock liquidity implies that issuance may signal environmental commitment, attract new investors and increase market visibility. Nanayakkara and Colombage (2019) provide complementary international evidence by showing that green bonds can trade at a premium relative to conventional securities, suggesting that investors are willing to accept less favorable yields in exchange for environmental attributes. This willingness can potentially improve financing conditions for issuers and support the mobilization of capital toward climate-related infrastructure. Hachenberg and Schiereck (2018), however, show that green-bond pricing differences vary across issuer categories and market segments, implying that environmental labeling does not generate a uniform financial effect. Conventional credit characteristics, issuer type and market structure continue to shape pricing outcomes. Fatica et al. (2021) reach a related conclusion by demonstrating that green-bond premia vary substantially according to issuer type, with non-financial corporations and financial institutions facing different pricing conditions. Taken together, these contributions imply that green-bond issuance can broaden the investor base and potentially reduce financing costs, but the magnitude of these effects depends on institutional characteristics, market structure and the financial profile of the issuer rather than on the green designation alone.

Larcker and Watts (2020) provide an important qualification to the proposition that green bonds systematically benefit from lower yields, as they find little evidence of a substantial greenium when comparing municipal green and conventional bonds with nearly identical credit characteristics. Their result implies that the financing advantage associated with environmental labeling is not automatic and may disappear in markets where comparable securities are easily identified and credit risk is closely matched. Zerbib (2019), by contrast, documents a modest negative yield premium using matched green and conventional bonds, suggesting that environmental preferences can still affect fixed-income pricing under certain conditions. The difference between these findings implies that investor segmentation, scarcity and market structure may determine whether green demand translates into measurable financing benefits. Fatica et al. (2021) further show that issuer characteristics condition the size of green-bond premia, indicating that investors do not value all green issuers equally. Hachenberg and Schiereck (2018) similarly find heterogeneous pricing effects across issuer categories and market segments. Considered together, these contributions imply that the existence and magnitude of a greenium depend on the interaction between conventional credit characteristics, issuer identity, investor demand and institutional market conditions. Green-bond policy therefore cannot rely solely on expanding labelled issuance but must also strengthen disclosure, credibility and project quality if environmental classification is expected to generate durable financing advantages.

2.2. Green-Bond Market Dynamics, Liquidity, Diversification and Scaling

Tolliver et al. (2020) show that the expansion of green-bond markets is closely connected to national climate-policy commitments, particularly those associated with the Paris Agreement. Their findings imply that clearer transition objectives can strengthen the supply of eligible projects, increase investor confidence and create conditions for financial institutions to expand sustainable debt instruments. Broadstock and Cheng (2019) complement this policy perspective by showing that the relationship between green and conventional bond markets varies over time according to macroeconomic conditions, uncertainty and investor sentiment. This implies that climate-policy support alone may not determine market expansion because broader monetary and financial conditions also influence the relative attractiveness of green securities. Wulandari et al. (2018) add a market-structure dimension by demonstrating that liquidity risk significantly affects green-bond yield spreads. Their results imply that sustainable debt instruments must provide sufficient secondary-market liquidity if they are to attract large institutional investors and support large-scale environmental financing. Pham (2016) further shows that green bonds display time-varying volatility and interactions across market segments, confirming that these instruments possess conventional financial-risk characteristics alongside their environmental purpose. Taken together, these contributions imply that scaling green-bond finance requires the interaction of credible climate commitments, favorable macro-financial conditions, adequate liquidity and a clearer understanding of volatility, rather than reliance on environmental labeling alone.

Reboredo and Ugolini (2020) demonstrate that green bonds are embedded in broader financial-market risk transmission, with meaningful price spillovers from fixed-income and currency markets and weaker connections with several other asset classes. This implies that green securities cannot be treated as an isolated environmental segment when investors assess portfolio risk or when policymakers consider financial stability. Reboredo (2018) reaches a related conclusion by documenting strong co-movement between green and conventional fixed-income securities but weaker dependence on equity and energy markets. The implication is that green bonds may provide some diversification benefits while remaining substantially integrated with the traditional bond market. Karpf and Mandel (2018) introduce a temporal dimension by showing that the value attached to the green label in the U.S. municipal market changed as the

market developed. Their findings imply that green premia evolve with market maturity, investor awareness and certification practices rather than remaining structurally constant. Broadstock and Cheng (2019) reinforce this interpretation by demonstrating that green–conventional bond connectedness itself changes with macroeconomic conditions and investor sentiment. Considered together, these studies imply that the risk and pricing characteristics of green bonds are dynamic and market-dependent. Their diversification potential and financing advantage can therefore change as financial conditions, investor participation and market maturity evolve. Baulkaran (2019) shows that corporate green-bond announcements can produce positive stock-market valuation effects, implying that investors may interpret green financing as a favorable signal about environmental strategy, future investment opportunities or stakeholder relations. Gianfrate and Peri (2019) provide a complementary financing implication by showing that green-bond issuance can reduce borrowing costs under certain market conditions, particularly when environmental use-of-proceeds commitments are credible. Their findings suggest that investor demand and reputational benefits may make sustainable debt economically attractive to issuers without depending exclusively on regulatory pressure. Karpf and Mandel (2018), however, show that the financial value attributed to the green label changes as the market matures, implying that early pricing benefits may weaken or transform as green securities become more standardized and widely available. Reboredo (2018) further demonstrates that green bonds remain strongly connected to conventional fixed-income markets, meaning that their attractiveness is also shaped by standard portfolio considerations such as correlation and diversification. Together, these contributions imply that firms may obtain both direct and indirect financial benefits from green-bond issuance, but these benefits depend on market maturity, credibility and portfolio characteristics. Green financing can therefore influence corporate value and borrowing conditions while remaining subject to the same changing market forces that shape conventional debt securities.

2.3. Green Banking, Central Banks and Macroprudential Financial Policy

Chenet et al. (2021) argue that climate-related financial risks are shaped by forms of uncertainty that conventional probabilistic models may not capture adequately. The implication is that regulators cannot rely exclusively on historical data or precise risk estimates when structural environmental change can alter future financial conditions in ways that remain difficult to quantify. Battiston et al. (2017) provide a complementary systemic perspective by showing that exposures to climate-policy-relevant sectors can be sufficiently concentrated to generate financial-stability consequences under an abrupt transition. Their stress-testing framework implies that banks and institutional investors should identify carbon-related exposures before more stringent policies transform asset values. Monasterolo and de Angelis (2020) reinforce the need for such intervention by showing that the Paris Agreement did not immediately produce a systematic stock-market revaluation consistent with firms' carbon intensity. This suggests that market prices may not spontaneously incorporate transition risks rapidly enough to redirect capital toward low-carbon activities. Campiglio et al. (2018) consequently place climate considerations within the responsibilities of central banks and financial regulators by linking physical and transition risks to financial stability. Taken together, these contributions imply that disclosure, stress testing and prudential supervision are necessary when market pricing and conventional risk models do not fully reflect the structural financial consequences of climate change. Dikau and Volz (2021) show that many central-bank mandates already contain objectives that can justify incorporating sustainability considerations even when environmental goals are not explicitly stated. Their findings imply that climate-related measures can be integrated into supervision, collateral frameworks and monetary operations when environmental risks affect price or financial stability. Campiglio (2016) provides an earlier foundation for this position by

arguing that carbon pricing may be insufficient to mobilize the financing required for a low-carbon transition. Because credit creation and financial regulation influence sectoral investment, adjustments to lending conditions can complement environmental pricing when low-carbon projects continue to face unfavorable risk-return profiles. Dafermos et al. (2018) extend this argument through a stock-flow consistent framework showing that climate damage and decarbonization interact with credit creation, asset prices and financial fragility. Their simulations imply that monetary institutions can affect both the speed and stability of transition through instruments that influence financial allocation. D'Orazio and Popoyan (2019) add a macroprudential dimension by examining differentiated capital requirements, exposure limits and related measures that can simultaneously address climate risk and encourage green investment. Together, these contributions imply that monetary and prudential policies can support ecological transition, but they should complement rather than replace carbon pricing, public investment and broader environmental regulation.

Cui et al. (2018) show that green lending may have a commercial rationale in addition to its environmental purpose, since stronger environmental performance among borrowers can be associated with lower credit risk. This implies that environmental information can become part of conventional credit assessment rather than functioning solely as a regulatory requirement. D'Orazio and Popoyan (2019) broaden this implication by showing how macroprudential instruments can modify banks' incentives toward environmentally sustainable lending, while also emphasizing the need to avoid excessive credit distortions or unintended instability. Campiglio (2016) similarly stresses that banking conditions influence which sectors obtain finance and therefore shape the capacity of low-carbon projects to attract investment when environmental pricing alone does not sufficiently alter project economics. Dafermos et al. (2018) place these lending decisions within a wider macro-financial system in which credit creation, asset prices, climate damage and transition policies interact. Their framework implies that changes in the direction of bank lending can affect both decarbonization and financial stability. Considered together, these contributions suggest that green credit policy can operate through an alignment between environmental objectives and financial-risk management. Its effectiveness, however, depends on the quality of environmental information, careful project selection and regulatory design capable of encouraging sustainable lending without undermining the stability of the broader financial system.

3. Financing the Ecological and Energy Transition

3.1. Renewable-Energy Investment and the Cost of Capital

Mazzucato and Semieniuk (2018) show that financing patterns in renewable energy differ according to technological maturity and risk, with public institutions often assuming a larger role during riskier development phases and private institutional investors entering once technologies and revenue structures become more established. This implies that ecological-transition policy should differentiate financial instruments according to the stage of technological development rather than treating renewable investment as a homogeneous financing problem. Hall et al. (2017) reinforce this interpretation by describing energy finance as an adaptive market in which investors evaluate low-carbon technologies through existing institutional structures, established practices and perceptions of risk. Their contribution implies that technological transformation also requires adjustment within financial institutions. Polzin et al. (2015) add that the effectiveness of public policy depends on technological maturity, since feed-in tariffs can be more appropriate for less mature technologies while market-based mechanisms become increasingly relevant as technologies develop. Credible long-term policies also reduce investment

uncertainty. Criscuolo and Menon (2015) extend this implication to green firms requiring venture capital, showing that supportive environmental policies can improve access to risk finance while unstable policy environments may discourage investors. Together, these contributions imply that mobilizing finance for ecological transition requires coordination between technology maturity, investor specialization, policy stability and financing instruments adapted to different forms of technological and commercial risk.

Egli et al. (2018) demonstrate that financing costs for renewable-energy technologies can decline substantially as markets mature and investors develop a better understanding of project risks. Their evidence implies that technological competitiveness depends not only on engineering costs but also on evolving costs of debt and equity across countries and technologies. Steffen (2020) reinforces this implication by showing that the cost of capital varies considerably across locations and technologies and directly influences levelized energy costs because renewable projects are highly capital intensive. Consequently, similar renewable resources can produce different investment outcomes when borrowing costs, policy risks and required equity returns differ. Steffen (2018) explains an important financial structure behind these outcomes by showing how project finance allocates risks among developers, lenders and other parties in projects characterized by high initial expenditure and relatively predictable operating cash flows. This structure means that regulatory uncertainty can directly affect renewable-electricity costs through financing conditions. Polzin (2017) broadens the discussion by identifying policy uncertainty, technological risk, information problems, weak project pipelines and mismatches between investors and projects as persistent barriers to private low-carbon finance. Taken together, these contributions imply that reducing renewable-energy costs requires attention to financial structures and perceived risk alongside technological progress, since better financing conditions can reinforce investment expansion as experience accumulates.

Hafner et al. (2020) argue that the green-finance gap cannot be reduced simply by increasing the number of individual sustainable financial instruments because policy uncertainty, short-termism, path dependency and institutional lock-in can continue to direct capital toward established carbon-intensive assets. Their systems perspective implies that ecological-transition finance requires broader institutional reforms capable of changing the incentives governing long-term capital allocation. Polzin (2017) reaches a compatible conclusion by showing that low-carbon projects may remain unfunded despite technical viability when policy uncertainty, information problems and financial structures make their risks unsuitable for private investors. His emphasis on combinations of public policy, de-risking measures and institutional innovation implies that no single financing mechanism can address all investment barriers. Mazzucato and Semieniuk (2018) further show why differentiated intervention is necessary, since different financial actors assume different roles according to the maturity and risk of renewable technologies. Public finance may therefore be particularly relevant when risks remain too high for private institutional capital. Egli et al. (2018) complement this argument by demonstrating that financing costs decline as markets mature, experience accumulates and perceived risks diminish. Together, these contributions imply that public intervention can help create conditions under which private finance progressively becomes more willing to support renewable technologies, while durable capital reallocation requires simultaneous changes in risk perception, institutional structures and long-term financial incentives.

3.2. Public Finance, State Investment and the Mobilization of Private Capital

Deleidi et al. (2020) show that public direct investment in renewable electricity can mobilize additional private capital rather than simply displacing it. This implies that the effectiveness of public finance should be assessed according to its capacity to reduce uncertainty, establish markets and generate subsequent investment opportunities. Mazzucato and Penna (2016) provide

an institutional explanation for this mechanism by showing that state investment banks can perform countercyclical, developmental, venture-capital and mission-oriented functions that extend beyond conventional market-failure correction. Their perspective implies that public financial institutions can assume risks and provide strategic direction where private investors are reluctant to finance long-term and uncertain low-carbon activities. Geddes et al. (2018) reinforce this argument through evidence from Australia, Germany and the United Kingdom, identifying capital provision, risk absorption, project facilitation, market creation and private-capital mobilization as important functions of state investment banks. Mazzucato and Semieniuk (2017) further show that public institutions frequently provide patient and high-risk finance before private actors are willing to participate. Taken together, these contributions imply that public and private finance should not be treated as substitutes. Public institutions can instead shape technological trajectories, absorb early-stage risks and create investable opportunities that subsequently attract commercial capital into ecological-transition projects.

Ameli et al. (2021) identify high financing costs as a source of a self-reinforcing climate-investment trap in developing economies. Expensive capital raises renewable-energy costs, slows market expansion and limits the accumulation of experience that could otherwise reduce perceived risk and financing expenses. This implies that technically attractive renewable projects may remain financially uncompetitive without external mechanisms that alter their risk-return conditions. Taghizadeh-Hesary and Yoshino (2019) address this problem by proposing credit guarantees and mechanisms that return part of the positive economic spillovers generated by green investment to project investors. Their approach implies that private participation can be strengthened by reducing risk and improving returns rather than depending solely on investors' environmental preferences. Banga (2019) adds an international distributional dimension by showing that the expansion of green-bond markets does not automatically provide developing countries with adequate access to climate finance because issuance costs, creditworthiness, limited market size and institutional capacity remain significant constraints. Polzin et al. (2019) further demonstrate that private renewable investment depends heavily on policy credibility, predictability and stability. Together, these contributions imply that closing the green-finance gap in developing economies requires coordinated de-risking, credible policy frameworks and stronger institutional capacity so that high financing costs do not prevent countries with substantial climate-investment needs from accessing private capital.

Monasterolo and Raberto (2018) show that green sovereign bonds and public green investment generate effects that extend beyond the financing of individual environmental projects because they interact with bank credit, employment, aggregate demand, public debt and financial stability. Their framework implies that ecological-transition financing must be evaluated through its broader macroeconomic consequences rather than solely through the volume of funds raised. Mazzucato and Penna (2016) complement this perspective by showing that public financial institutions can actively shape markets and direct investment toward missions characterized by long horizons and substantial public spillovers. This implies that public finance may influence not only project availability but also the structural direction of economic transformation. Deleidi et al. (2020) provide empirical support for such a catalytic role by demonstrating that public renewable investment can crowd private capital in rather than crowd it out. Polzin et al. (2019) add that this mobilization depends strongly on stable and credible renewable-energy policies because even generous incentives may fail when investors expect regulatory reversals. Considered together, these contributions imply that public ecological-transition finance is most effective when fiscal instruments, public financial institutions and renewable-energy policies operate coherently. Such coordination can create markets, support macroeconomic activity and encourage additional private investment while reducing the uncertainty that otherwise constrains long-term green capital formation.

3.3. Corporate Green Investment, Green Credit and Transition Financing in Emerging Economies

De Haas and Popov (2023) show that the structure of the financial system can influence the pace of green transformation, as carbon-intensive industries reduce emissions more rapidly where stock markets are deeper and better able to finance innovation. The implication is that ecological transition depends not only on specialized green instruments but also on access to risk-bearing equity capable of supporting uncertain technological change. Touil et al. (2024) complement this perspective at firm level by showing that sustainability-oriented practices such as green technologies, sustainable contracting, sourcing optimization, transparency and traceability can contribute positively to corporate financial performance. Their findings imply that environmental investment can support competitiveness when it is integrated into organizational and supply-chain management rather than treated solely as a compliance cost. Meo and Abd Karim (2022) extend this relationship to the macroeconomic level by finding that greater green finance is generally associated with lower carbon emissions, although the strength of this relationship varies across countries and market conditions. Touil et al. (2023) provide a further organizational implication by linking greener supply-chain adoption to stakeholder pressures, incentives and economic conditions. Taken together, these contributions imply that ecological transition requires financial systems capable of directing capital toward both technological innovation and ordinary corporate investment decisions, while the environmental and financial outcomes remain dependent on institutional, organizational and market conditions.

Yin et al. (2023) show that green-credit policy can produce unintended effects when tighter financing constraints reduce both the quantity and quality of green innovation among polluting firms, particularly non-state-owned enterprises. This implies that restricting credit to environmentally intensive firms may weaken their capacity to finance the technologies required for transition unless alternative financing mechanisms are available. He et al. (2025) provide a contrasting outcome by showing that green-credit policy can increase corporate environmental innovation when it alleviates financing constraints and reduces financing costs, with effects differing according to ownership, industry and digital capabilities. The comparison implies that the effectiveness of green credit depends strongly on institutional design and borrower characteristics. Yu et al. (2021) reinforce this conditional interpretation by showing that green-finance policies can mitigate financing constraints on corporate green innovation, while privately owned firms receive less benefit from green credit than state-owned enterprises. Xing et al. (2021) add an informational dimension by demonstrating that green innovation can improve access to bank lending, whereas environmental disclosure alone may not do so when its credibility is weakened by low-quality reporting or greenwashing. Together, these contributions imply that transition finance requires not only greater credit volumes but also equitable access, credible environmental information and mechanisms that distinguish substantive ecological transformation from symbolic environmental claims.

4. Discussion

The literature first demonstrates that the contribution of sustainable finance to ecological transition depends considerably on the quality and interpretation of environmental information. Hartzmark and Sussman (2019) show that accessible sustainability ratings influence investment flows, indicating that standardized ESG information can modify capital allocation even without immediate changes in conventional financial characteristics. Khan et al. (2016), how-

ever, emphasize that the financial relevance of sustainability depends on materiality, which limits approaches that treat all ESG indicators as equally informative. This qualification is reinforced by Berg et al. (2022), who document substantial divergence among ESG rating agencies resulting from differences in scope, measurement and weighting. Avramov et al. (2022) similarly show that disagreement surrounding ESG assessments can influence portfolio construction and reduce the attractiveness of sustainability strategies when informational uncertainty increases. These findings help explain why the relationship between sustainability and financial performance remains conditional. Friede et al. (2015) find that ESG performance is predominantly associated with non-negative corporate financial outcomes, whereas Revelli and Viviani (2015) show that socially responsible investment does not systematically outperform conventional investment. Sustainable finance should therefore not be evaluated according to an expectation of automatic superior returns. Its financial role depends instead on whether environmental information identifies economically relevant exposures and allows investors to differentiate more effectively among firms. This informational function becomes increasingly important as climate considerations affect conventional risk assessment and expected financial performance. A second result concerns the capacity of green financial instruments to translate environmental preferences into financing conditions. Flammer (2021) shows that corporate green-bond issuance may generate favorable market reactions, improve environmental performance and attract longer-term investors, particularly when bonds receive external certification. Hyun et al. (2020) and Bachelet et al. (2019) similarly emphasize that certification and verification strengthen investor confidence and can increase the pricing advantages associated with green securities. Zerbib (2019) identifies a modest green-bond yield premium, indicating that environmentally oriented demand may reduce issuer financing costs, although Larcker and Watts (2020) find little evidence of a systematic greenium after closely matching conventional and green municipal bonds. This contrast suggests that environmental labeling alone cannot explain pricing outcomes. Issuer characteristics, market segmentation, liquidity and institutional conditions remain important, as also indicated by Fatica et al. (2021) and Hachenberg and Schiereck (2018). Green finance therefore depends strongly on credibility and market structure. This conclusion extends to banking and financial regulation. Cui et al. (2018) show that environmental performance may be associated with lower credit risk, while D'Orazio and Popoyan (2019) explain how macroprudential instruments can influence banks' incentives toward sustainable lending. Consequently, environmental finance becomes more effective when green instruments are integrated with conventional risk-management practices rather than treated as independent financial categories.

The third major implication is that ecological transition requires coordinated public and private financing rather than exclusive reliance on market-based mechanisms. Mazzucato and Semieniuk (2018) show that different financial actors enter renewable-energy projects according to technological maturity and risk, with public institutions frequently taking greater exposure during uncertain development phases. Egli et al. (2018) and Steffen (2020) demonstrate that renewable-energy competitiveness is significantly affected by the cost of capital, indicating that technological progress alone is insufficient when financing remains expensive. This problem is particularly significant in developing economies. Ameli et al. (2021) describe a climate-investment trap in which high financing costs increase renewable-energy costs, slow market development and prevent the accumulation of experience that could reduce perceived risk. Public intervention can alter these conditions. Deleidi et al. (2020) show that public renewable investment can stimulate rather than displace private investment, while Mazzucato and Penna (2016) and Geddes et al. (2018) emphasize the role of state investment banks in risk absorption, project development and market creation. At the corporate level, De Haas and Popov (2023) further

show that financial-system structure affects the capacity of carbon-intensive industries to finance innovation, while Touil et al. (2023, 2024) demonstrate that sustainability-oriented corporate and supply-chain investments can be connected to economic incentives and financial performance. The transition therefore depends on combining financial-market development, public risk sharing, credible policy and firm-level investment incentives.

Conclusion

The literature reviewed in this paper shows that sustainable finance has become an important component of the broader institutional architecture supporting ecological transition. Its contribution operates through several interconnected channels, including ESG integration, environmental-risk pricing, green bonds, green banking, public finance and corporate green investment. Environmental considerations increasingly influence investor demand, portfolio composition, borrowing conditions and financial regulation. Nevertheless, these effects are not uniform. ESG ratings may facilitate investment decisions while simultaneously generating uncertainty when methodologies diverge. Carbon and climate risks can affect expected returns and financing costs, but their pricing depends on investor awareness, beliefs and regulatory expectations. Similarly, green bonds can provide financing advantages, although these benefits depend on certification, issuer credibility, liquidity and market conditions. Sustainable financial instruments should therefore not be considered inherently effective simply because they carry an environmental label. Their contribution depends on the institutional structures that support disclosure, verification, risk assessment and credible environmental commitments. The central implication is that sustainable finance contributes most effectively to ecological transition when environmental information is sufficiently reliable to alter conventional financial decisions and when financial incentives are aligned with measurable environmental outcomes.

The financing of ecological transition also requires a broader perspective extending beyond individual financial products. Renewable-energy projects and emerging green technologies frequently involve high upfront investment, long maturities and risks that private investors may be unwilling to assume independently. Public financial institutions, guarantees and direct investment can consequently reduce uncertainty, support market formation and mobilize additional private capital. These mechanisms are particularly relevant in developing and emerging economies where high financing costs and limited institutional capacity can restrict otherwise viable low-carbon investments. At the same time, transition finance must extend to existing firms and production systems rather than concentrate exclusively on specialized green projects. Financial-system development, green credit, corporate innovation and sustainable supply-chain investment influence firms' capacity to modify technologies and business practices. The evidence therefore supports a coordinated approach in which public policy, private finance, banking systems and corporate investment decisions operate jointly. Ecological transition cannot be financed solely through increased volumes of green capital; it also requires credible regulation, appropriate risk-sharing arrangements, reliable environmental information and institutions capable of directing long-term financial resources toward structural economic transformation. Sustainable finance should consequently be understood as a mechanism for reorganizing capital allocation in accordance with both financial constraints and environmental objectives.

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