

Algorithmic Stewardship for Sustainable Finance: Governing AI, ESG Integrity, and Green Supply Chains

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Abstract

The increasing convergence of Green Financial Technology (Green FinTech), artificial intelligence (AI), and sustainable supply chain finance may suggest that these developments could transform how organizations evaluate environmental performance, allocate financial resources, and achieve Environmental, Social, and Governance (ESG) objectives. Moreover, the existing research largely concentrates on technological implementation and ESG measurement, while paying limited attention to governance mechanisms that could ensure financial integrity, stakeholder trust, and substantive sustainability outcomes. Furthermore, this paper develops a conceptual framework of algorithmic stewardship for green supply chains by integrating agency theory, stakeholder theory, environmental ethics, and emerging principles of AI governance. Given that the framework proposes four key antecedents, the evidence may indicate that carbon data transparency, algorithmic explainability, supply chain data quality, and Green FinTech governance controls appear critical. Evidence shows factors influence decision quality. Nevertheless, these factors might influence green financial decision quality, substantive ESG compliance, and integrity risk reduction through the mediating roles that human ethical judgment and digital stakeholder trust could demonstrate. However, board-level green-tech competence and regulatory environment stringency may appear as critical boundary conditions shaping these important relationships. In light of these findings, the study might advance the literature on sustainable finance and responsible AI while offering a practical roadmap for designing transparent, trustworthy, and ethically governed green financing ecosystems. Moreover, the framework could provide that a foundation for future empirical research examining how algorithmic stewardship may support resilient, inclusive, and sustainability-oriented supply chains appears relevant. Research shows framework supports chains.

Keywords: Algorithmic Stewardship, Green FinTech, Sustainable Supply Chain Finance, Corporate Financial Integrity.

1. Introduction:

There are two paradigm shifts in the corporate finance domain one towards digitalization and another towards sustainability in the supply chain. Supply chain finance (SCF) has served as a means of working cap improvement via transactional liquidity instruments like dynamic discounting, supplier early-payment programs, and reverse factoring for years. In the interim, the pressure on corporations has been growing to include the full picture of carbon emissions, which can include Scope 3 carbon emissions, the type of emission that can represent up to 70%-90% of a multinational company's total footprint and that occurs largely from upstream supply chains. The rise of Green Fintech is the digital link between environmental performance and financial liquidity. New APIs for real-time carbon accounting, blockchain-based traceability, automated ESG data scrapers, and flexible credit-scoring models allow companies to now automate the evaluation of supplier sustainability data and dynamically modify loan parameters based on those new insights. Suppliers who reduce their emissions, adopt renewable energy or use resources more efficiently are able to access capital, improve interest rates, or receive quicker payment on their invoice. As a group, the field of supply chain finance has expanded greatly. Initially, it was considered as a financial-logistics integration problem, which would involve sharing the creditworthiness of the parties involved in purchasing and selling of goods and services, thus minimizing funding costs and cash conversion cycles ([Gelsomino et al., 2016](#)). At the same time, research on sustainable supply chain management showed that focal companies actually include their sub-suppliers in their environmental and social endeavors, forcing buyers to track and manage sub-supplier performance some levels back ([Seuring & Müller, 2008](#)). The research on digital finance, on the other hand, presents the effects of platform-based technologies on financial services delivery ([Gomber et al., 2017](#)). Green Fintech is a nexus of these three flows and new governance questions arise there. While there are significant opportunities for the use of Green Fintech and supply chain finance, there are numerous governance issues.

Despite, the use of credit-scoring models, automated ESG rating algorithms, and opaque risk-assessment engines are done without much human oversight. Financial incentives, liquidity allocation, and contract terms are automated, and there is a high level of accountability fragmentation. There is evidence of a significant variation in ratings across different ESG providers, even across the measures of the same constructs ([Berg et al., 2022](#)). Human designed rating methodologies create problems of their own and measurement error is compounded even further if such an automated rating is directly tied to liquidity decisions. The score might be so complex that the supplier or their finance team is unable to really comprehend the score, but the buyer may only rely on the score to decide whether or not they will be providing the supplier with the working capital that it requires. Traditional financial governance ([Jensen & Meckling, 1976](#); [Eisenhardt, 1989](#)) and strategic stakeholder management ([Freeman, 1984](#)) theories have been thoroughly discussed in literature, but there is limited research discussing the theoretical implications of the effect Of automated, data-driven green financial systems on corporate integrity, stakeholder trust, and meaningful ESG compliance. This paper proposes to address this gap by providing a comprehensive theoretical framework based on agency theory, stakeholder theory as well as environmental ethics and its application to a Green Fintech in supply chain finance. This paper thus addresses five research questions:

RQ1. What are the impacts of the design features of Green Fintech platforms—transparency, explainability, data foundations, and governance controls—on the integrity of the corporate outcome in sustainable supply chain finance?

RQ2. How do these technical features get translated into mechanisms - human and relational that make better decisions and more credible ESG performance?

RQ3. What kinds of organizational and institutional environments promote or hinder these relationships?

RQ4. May examine how adaptive algorithmic stewardship could maintain financial integrity and sustainability performance under continuously evolving AI systems.

RQ5. Appears to explore what governance mechanisms might prevent exclusion of smaller suppliers in AI-enabled sustainability financing ecosystems.

2. Theoretical gaps and problematization

The application of a years in the field of sustainable supply chain management poses important theoretical questions and challenges of classical organizational and financial theory. A number of further questions and challenges arise in the context of classical organizational and financial theory. This study is driven by three theory tensions: The role of marketing in a business (Section 2.2); and The distributed-harm tension in multi-tiered stakeholder networks and Transparency of process around green financial reporting (Section 2.3). This section introduces the ontological tension in agency-driven supply chains. The Ontological Tension in Agency-Driven Supply Chains.

2.1 introduces the ontological tension: According to classical agency theory, the firm is a collection of contracts that can alleviate the information asymmetries, and bring the principals' (shareholders' or buyers') faith back in the agents' (managers' or suppliers') actions via bonding, monitoring, and incentives (Jensen and Meckling, 1976; Eisenhardt, 1989). In Green Fintech, however, key evaluation and allocation decisions are frequently carried out by automated algorithms instead of by human financial officers. Unlike humans, AI models and green-scoring engines have no intentions, moral agency, self-interested preferences, but it affects capital allocation, credit limits, and financing costs for thousands of upstream suppliers. The classical agency problem is then replaced by one of monitoring and controlling an agent who is uninhabited and a computational system (which is the actual allocator of the financial capital), whose design, data provenance, model architecture and behavioral feedback loop are what make it a non-sentient agent. This change has an important corollary. Traditionally, monitoring costs have been viewed as being the result of an agency problem, and remuneration adjusted to reduce the incentive for agents to shirk, or monitoring expanded to reduce the incentive for agents to shirk (Jensen & Meckling, 1976; Eisenhardt, 1989). An algorithm does not have interests of its own, but it can still produce results that are not aligned with the real interests of the principal, for example, to maximize some visible and measurable proxy (e.g., reported emission intensity) instead of with the actual environmental interests. The disconnect is not because of opportunism, but specification, training and deployment context, and the governance toolkit needs to take into account these causes. The responsibility, not for the algorithm itself, but for the humans and institutions that commission, configure and rely on the algorithm.

2.2 Multi-Tiered Stakeholder Networks: Distributed Harm

The expectation of the stakeholder theory was that the definition of corporate responsibility would be expanded to include anyone who is impacted by a company's actions (Freeman, 1984). However, algorithmic decision making in multi-tiered global supply chains has a distributed impact on stakeholders. The lack of carbon emissions data in some suppliers, the use of historical proxy metrics, and biased reporting standards among regions make it easy for tier-2 or tier-3 suppliers to be overlooked for liquidity and subject to systematic penalties. These negative impacts result from multiple, multivariable algorithmic interactions across large supplier networks and are hard to track and address using traditional stakeholder engagement approaches. This research trend also illuminates the potential for such harms. In part, automatic systems trained on historical data can replicate patterns of disadvantage because data are themselves a pattern of past disadvantage, and in part because seemingly innocuous variables are proxies for characteristics that were never intended to be relevant (Barocas & Selbst, 2016). This can be for an organization's size, geographic location, or even third party certification. The algorithm may give a low score to a small supplier from a developing economy, because they may have low emissions, but may not have the resources to document them. The same goes for fairness itself where there are no technically defaulted natural features (as philosophical analyses remind us, Binns, 2018); fairness is a contested concept, with multiple and often competing definitions. In addition, the theory of stakeholder salience, developed by Mitchell et al., 1997, states that stakeholders whose legitimacy is not low but power and urgency are not high are most likely not to be listened to.

2.3 Process Opacity in Green Financial Reporting

Regulatory bodies are increasingly demanding highly detailed information on ESG and Scope 3 performance (mentioned in Introduction Part), while methodology applied by green fintech platforms to generate results is opaque. A "black box" algorithm can be used to calculate the carbon reduction of a supplier, while simultaneously taking into account the financial discount rates. Organizations can be tempted to use 'digital greenwashing' (automated sustainability metrics that mask actual environmental damage), and suppliers with actual sustainable projects may be hit with penalties due to technical artifacts, if they aren't transparent about the algorithms. The issue of opacity is further complicated by the fact that the environmental claims in the reports do not necessarily match environmental performance. Selective disclosure and symbolic action have been linked to greenwashing, and they are driven by regulatory, market and organizational pressures (Delmas & Burbano, 2011). At scale this can be tacitly institutionalized by automated reporting pipelines that foster the generation of superficially pleasing metrics rather than actual decarbonization, where the platform can incentivize suppliers to report to it on the basis of favorable data, without verifying its authenticity. There is also a need for transparency for fair treatment of suppliers, and for the integrity of the purchaser's own sustainability reporting and claims as investors and regulators may subsequently learn that the "headline numbers" were based on unverifiable algorithmic outputs. The three tensions are mutually dependent and all three together require a framework where governance, transparency and human judgment are treated as an essential.

3. Theoretical Foundations

In order to construct a solid model of Green FinTech in supply chain finance, this paper integrates four complementary theories (as shown in Figure 1).

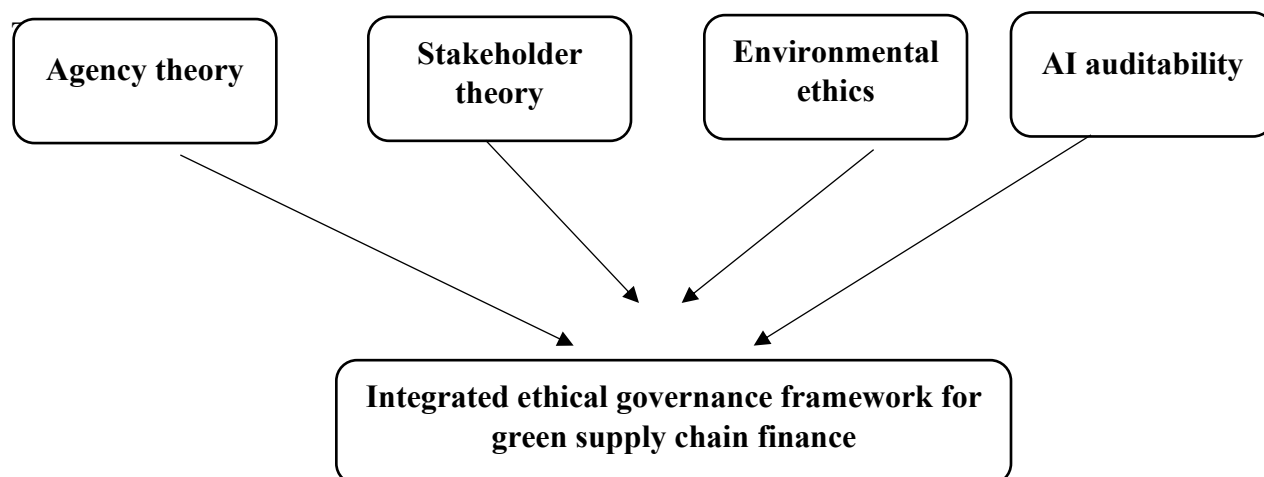


Figure 1. Theoretical aspects of the Ethical Green FinTech Governance Framework.

3.1 Research Agenda for the Next Decade

- **Agentic AI in Sustainable Finance:** In sustainable finance, Agentic AI powers the ability for financial institutions to automatically evaluate ESG performance, identify sustainability risks and investment opportunities, and manage financial risk in a faster, more informed and more sustainable way.
- **ESG Digital Twins:** Traditional environmental, social and governance reports are published periodically and do not provide continuous insight into a company's or fund's carbon emissions, resource consumption, social impact, etc. ESG Digital Twins provide continuous monitoring and enable more accurate and timely decisions for organizations and investors.
- **AI Audit Governance:** The goal of AI Audit Governance is to ensure AI is transparent, ethical, and in compliance with laws and regulations. Regular audits of AI can identify biases, errors, and risks, which can impact accountability and stakeholder trust.
- **Blockchain Carbon Verification:** Information recorded on a Blockchain cannot be easily altered, it provides a reliable and trustworthy way to record environmental data. It reduces the risk of false carbon reporting.
- **Climate-Risk-Aware Lending Algorithms:** These algorithms consider factors such as natural disasters, carbon emissions, environmental regulations, and environmental and social performance. By accounting for climate risks, financial institutions can reduce potential losses.
- **Human-AI Joint Governance:** AI provides data analysis, predictions, and recommendations and humans make the final decision and ensure ethical judgment.

Human-AI Joint Governance combines the benefits of AI and human experience, accountability, and critical thinking.

- **Digital Product Passports:** It can include data about materials, manufacturing, carbon footprint, end-of-life recycling options, supply chain, etc. Digital Product Passports provide transparency to consumers and can empower them to make informed decisions. They also support other sustainability goals such as the circular economy.
- **Autonomous Sustainability Ecosystems:** Autonomous Sustainability Ecosystems can automatically detect problems, optimize resource consumption, reduce waste, and make decisions with little or no human input. Their goal is to improve environmental performance and operational efficiency in a self-regulating way.
- **Supplier Inclusion Algorithms:** Supplier inclusion algorithms are an application of AI to assist in fair and inclusive supplier inclusion, based on objective criteria such as performance, sustainability performance, quality and reliability of supply. The algorithms remove bias from procurement, and provides equal opportunities for small and local suppliers and diverse suppliers to be included in procurement.
- **Cross-Border ESG Data Governance:** Sustainability reporting requirements differ across countries and regions, there is a need for uniform rules on how ESG data is collected, shared, protected and verified by companies. Effective cross-border governance helps ensure consistent data quality, compliance with regulations and improves the overall global sustainability report.

3.2 Extended Agency Theory

When financial authority is delegated, agency theory offers insights into the reasons for oversight, control mechanisms, and the design of contracts. Here, model transparency, data verification controls and algorithmic auditability become substitutes for the traditional agency theory monitoring and bonding mechanisms ex-ante. The reasoning is different from the one in the original agency theory; it has changed. This is the same information asymmetry issue, only this time it's between the technical staff creating and maintaining the scoring models and the staff that use it, including the financial staff, board members and suppliers. The contractual covenants are replaced by bonding mechanisms like model documentation standards, independent validation and audit trail, while monitoring is given away for continuous testing of drift, bias and data corruption. From this perspective, it can be assumed that agency costs are either raised or lowered under delegated green financing decisions depending on the quality of the ex-ante controls, based on the extended agency theory.

3.3 Stakeholder Theory

Stakeholder theory demands that businesses take into account all stakeholders, including their suppliers, communities and "green" consumers. However, sustainable supply chain finance must be trusted by all stakeholders to be fair, legitimate and developmental in nature, or it will not work. Stakeholder theory is usefully reduced to three versions: descriptive, instrumental and normative (Donaldson & Preston, 1995) which are all applicable here. Green financing algorithms are evident in the case of upstream suppliers. Fairness is instrumental to better supply chain resilience, cooperation and further emission reductions. Normatively, the suppliers have the right to be considered based on clear and open criteria, even if this is not beneficial for them financially.

3.4 The ethical and principled application of AI

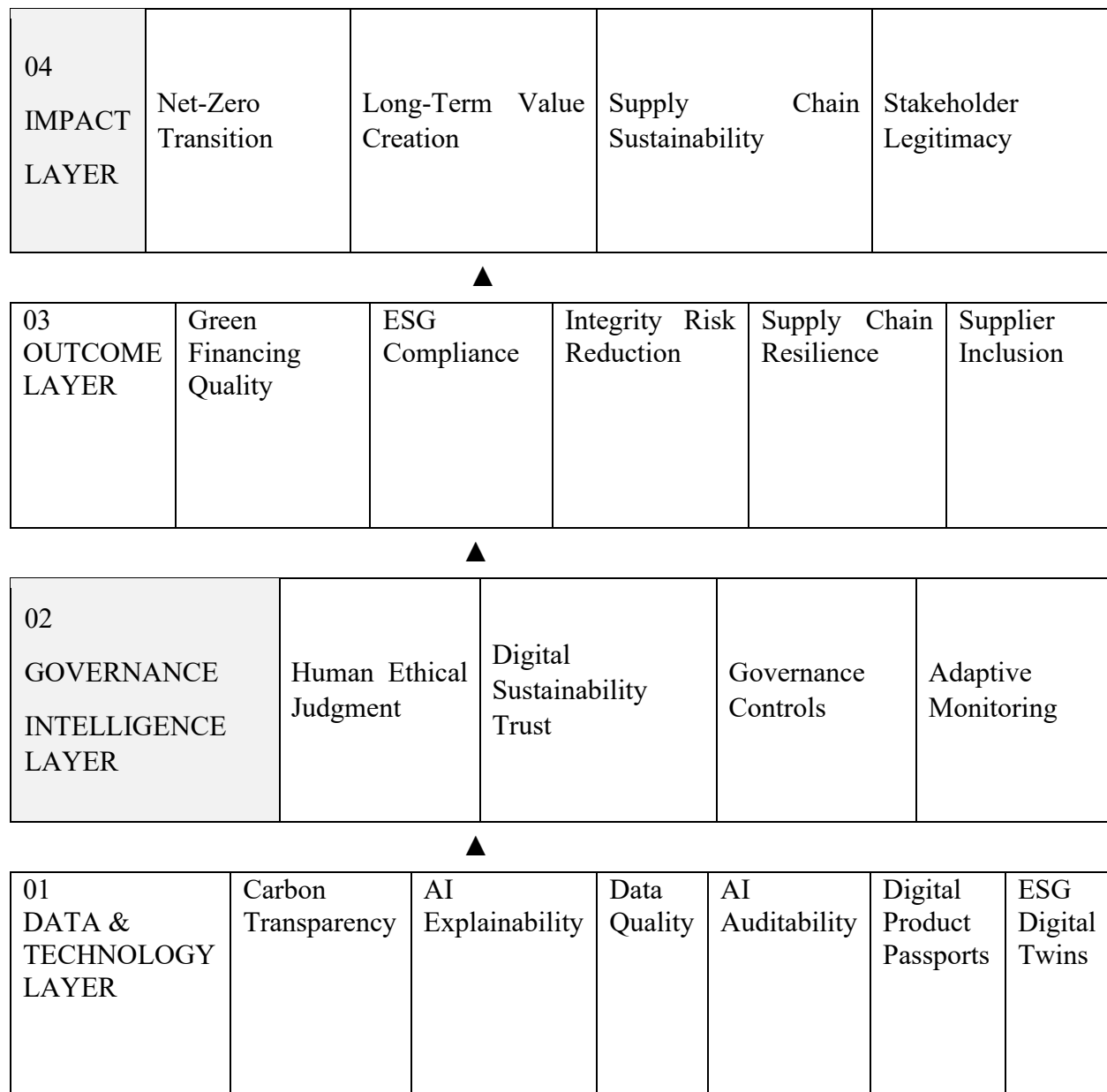
In the environment. AI's ethical and principled use in the environment. The use of environmental ethics (ecological justice, non-maleficence, sustainability) in conjunction with the principle approach to AI ethics (Floridi et al., 2018) can guarantee that green financial technologies actively respect ecological boundaries and human rights along the value chain. The impetus of this approach is to emphasize the importance of technological efficiency and to reinforce the ethical responsibilities of the platform operators with respect to suppliers in a situation of fragility and low resources. There are common values that underpin principled approaches to AI ethics (Floridi & Cows, 2019). When comparing guidelines from different countries, transparency, justice and fairness, non-maleficence, responsibility and privacy were most common among the listed principles (Jobin et al., 2019). In this Green FinTech vision, these principles are well aligned with design requirements, such as: disclosure of the scoring logic, a proxy variable check on fairness, and a vulnerable supplier protection check on no malfeasance. However, principles are not sufficient; a critical analysis of algorithmic accountability also reveals this is not the case (Martin, 2019; Mittelstadt et al., 2016). These require organizational structures and professional reasoning to be implemented, thus the suggested framework combines technical antecedents and human process mediation.

3.5 Complementary perspective:

Institutional Theory and Trust People are often given the opportunity to participate in activities that are meaningful to them. Individuals are afforded the chance to engage in activities with meaning. The centerpiece of the framework is three theoretical viewpoints, with two complementary literatures linking to the mediating and moderating concepts. The institutional theory suggests that organizations respond to external demands to gain legitimacy and that the ways in which they respond to these demands are by mimetic, normative, and coercive pressures (DiMaggio & Powell, 1983). The pressure of climate disclosure, the mimetic pressure Of Other companies adopting green scoring platforms and the normative pressure of professional standards for model risk management and sustainability assurance are all sources of pressure. These forces form the basis of the treatment of the regulatory stringency as a boundary condition. The trust literature, on the other hand, specifies trustworthiness by means of perceived ability, benevolence, and integrity (Mayer et al., 1995). So in essence, when suppliers are thinking about utilizing a buyer's green financing program, they are asking, is it capable, are the designers being honest, and is it following the principles of sound financing? This logic has been at the heart of the mediating role of stakeholder trust. The Green FinTech Transition Plan We follow (Jaakkola, 2020) and suggest an integrated framework with four antecedents, two mediating mechanisms, three key organizational outcomes, and two boundary conditions (Figure 2)

Layered Architecture for Ethical Governance in Green Supply Chain Finance

From data and technology foundations to long-term impact



Source of Figure 2 The Green FinTech Supply Chain Governance Framework (From 6.Synthesis of Construct Table 1).

4. Antecedent Conditions

- Carbon and Green Data Transparency: Transparency on the measurement, weighting and tracking of emissions and environmental credentials of suppliers on fintech platforms.
- Algorithmic Explainability: The technical capacity of the green financing platform to give reasons for a specific supplier's sustainability score or financial discount.
- Supply Chain Data Quality: The level of accuracy, completeness, timeliness and unbiased data supplied from various levels of the supply chain.

- **Green Fintech Governance Controls:** Organizational controls, automated audit controls, model-risk controls and human-in-the-loop override controls for the roll-out of sustainable financing algorithms.

The four antecedents are complementary, but conceptually different. Transparency is about what is shown in the platform, explainability is about how the individual outputs on the platform can be explained, data quality is about the inputs that the outputs depend on and governance controls are about the structures that surround the platform. Data quality is particularly important since it is multi-dimensional and there are four dimensions of data quality, intrinsic accuracy, contextual fit, representational clarity, and accessibility (Wang & Strong, 1996). Explainability can be obtained through building inherently interpretable models or by using post hoc techniques that shift from a black box to a glass box (Rai, 2020). In particular, counterfactual explanations can help people affected by a model understand what changes would be required in order to have a different outcome, while not revealing the underlying model (Arrieta et al., 2020; Wachter et al., 2018). The supplier would be better served by an understanding of which emission reduction activities would turn the tide towards financing than by a black box score.

4.2 Mediating Mechanisms Human Ethical Judgment:

Moral and professional judgment of the corporate finance officers, supply chain managers, and credit committees in relation to the algorithmic recommendations for green financing. Upstream Stakeholder Trust: Trust from suppliers, investor and regulators in the integrity, sustainability and transparency of the green financial environment. These mediators are the human and interpersonal processes which influence whether technical measures result in different outcomes. Ethical judgment is a form of questioning, interpretation and sometimes rejection of algorithmic recommendations. By contrast, trust involves acceptance of the system as legitimate, and greater willingness to cooperate, such as by providing granular emissions data more readily. The two mediators are expected to back each Other up: improved trust in decision makers is expected to lead to improved data-sharing from suppliers, which should lead to improved judgment, which should lead to greater trust in decision makers.

4.3 Outcomes and Boundary Conditions: Outcomes: This framework has three outcomes: Green Financial Decision Quality (accuracy and risk-appropriateness of capital allocation); Substantive ESG Compliance (genuine reduction in Scope 3 emissions); and Reduced Integrity Risk (mitigation of financial misconduct, greenwashing liabilities and regulatory penalties). Boundary conditions: Two boundary conditions were chosen: technical and environmental competence of senior leadership (Board Green-Tech Competence) and stringency of global climate disclosure mandates and AI laws (Regulatory Environment Stringency).

4.4 Integrative Logic of the Framework The premise of the framework is the seemingly obvious one that the outcomes of green finance platforms do not only rely on their technical design, but also on the organizational and relational processes that the design allows for. Transparency and explainability provide information that enables human decision makers and suppliers to assess algorithmic outputs. These outputs are grounded in sound inputs through data quality and governance controls, and are subject to systematic oversight. Under such circumstances, the finance officers are able to make ethical decisions more easily, and suppliers will feel more confident in the system. Judgment and trust then converts to better allocation of capital, real emission reductions and a reduced likelihood of wrongdoing and regulation fines.

5. Formal Propositions

The next sixteen conceptual propositions are formulated to inform future empirical studies

No.	Proposition
P1	Greater carbon data transparency on green fintech platforms is positively associated with upstream stakeholder trust.
P2	The more readily algorithms can be explained, the more effectively humans can exercise ethical judgment in sustainable supply chains.
P3	The higher the quality of supply chain data, the higher the quality of green financial decisions and the lower the integrity risk, especially when verification controls are effective.
P4	Rigorously enforced governance controls over green algorithms are positively associated with ethical human oversight and stakeholder trust.
P5	Human ethical judgment mediates the relationship between green fintech antecedents and green financial decision quality, enabling effective assessment of the outputs of automated processes.
P6	Stakeholder trust mediates the relationship between governance antecedents and substantive ESG compliance.
P7	Together with ethical judgment, stakeholder trust reduces integrity risks in sustainable supply chain finance, including greenwashing and regulatory sanctions.
P8	Board-level green-tech competence positively moderates the relationship between algorithmic explainability and human ethical judgment, such that the relationship is stronger when competence is high.
P9	Regulatory environment stringency positively moderates the relationship between governance controls and stakeholder trust.
P10	Sustainability financial incentives perceived as fair and transparent accelerate suppliers' decarbonization efforts significantly more than punitive mandates do.
P11	AI auditability positively influences digital sustainability trust.
P12	Digital sustainability trust mediates the relationship between AI auditability and substantive ESG compliance.
P13	Adaptive algorithmic stewardship positively enhances supply chain resilience.
P14	Responsible AI capability strengthens the impact of governance controls on financing decision quality.
P15	Organizations using ESG Digital Twins achieve higher financing accuracy than organizations using periodic sustainability reporting.

P16	Algorithmic fairness safeguards positively influence sustainable supplier inclusion.
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The propositions are broken down in three groups by the kind of relationship they express. P1—P4 explain the immediate effects of the four antecedents on the mediation processes, and for P3, on the outcomes. Transparency and explainability enable stakeholders and decision makers to make informed decisions, which is in line with the focus on perceived ability and integrity in the trust literature (Mayer et al., 1995). P3 also takes from the data quality literature, which has determined that the complexity of the information model is not sufficient enough to make up for these poor quality input data (Wang & Strong, 1996). The mediating architecture is given by P5—P7. These propositions suggest that the technical "foresight" can enhance outcomes primarily by enabling human ethical judgment and maintaining the trust of stakeholders—not automatically. This is in line with the argument of responsibility shifting, which is that responsibility for an algorithm's outcomes cannot be delegated to the algorithm itself (Martin, 2019). P7 also suggests that judgment and trust are complementary in helping to mitigate integrity risks: judgment can prevent poor internal decisions to be made, and trust can help deter adversarial supplier conduct, such as data manipulation, because of perceived unfairness. Boundary conditions and a behavioral outcome are addressed in P8—P10. P11 means that when AI is transparent and its review, monitoring, or audit is easy, people trust the digital sustainability practices of the organization. When people can see how AI is making decisions, they trust that the organization is using AI responsibly and ethically.

P12 means that AI auditability can lead to improved ESG (Environmental, Social, and Governance) compliance, because transparent and auditable AI leads to trust in sustainability practices. Trust is the correlating variable that bridges transparent AI and improved ESG.

P13 means that when a company changes and continuously improves its AI algorithms, it can have a more resilient supply chain. Adaptive algorithms can adjust fast enough to deal with disruptions, risks, and changes in market conditions.

P14 means that responsible AI makes the governance system more effective at supporting high-quality financing decisions. Responsible AI ensures that financial analyses are done correctly and are fair, transparent, and unbiased (or at least not unnecessarily biased).

P15 means that organizations making use of ESG Digital Twins (real-time digital twin of sustainability performance) make better financing decisions, relative to organizations that make financing decisions based on one-period-later sustainability reports.

P16 means that an organization that uses fairness protections for its AI can ensure that it is treating a greater and more diverse set of suppliers fairly. Fairness protections ensure that there is no bias and that there are equal opportunities for suppliers, particularly small or underrepresented suppliers. Organizational capability and institutional pressure (DiMaggio & Powell, 1983) affect the effectiveness of technical safeguards, say P8 and P9. P10 is about incentive design: suppliers are expected to react more to a financial reward that is considered a real incentive than to any punishment. This is a proposition that aligns with the stakeholder-theory notion that a sense of fairness has a direct impact on cooperation (Donaldson & Preston, 1995), which is particularly relevant for the design of sustainability linked financing programmes. The ten propositions provide a testable road map for continuing empirical research.

6. Synthesis of Construct

The constructs of the framework, their functions, and theoretical foundations are summarized in Table[1].

Table 1. Synthesis of construct

Construct	Type	Concise definition	Theoretical origin
Carbon/Green Data Transparency	Antecedent	Transparency of metrics and operational logic of green fintech tools.	Agency Theory; AI Ethics
Algorithmic Explainability	Antecedent	Capacity to explain factors that affect a supplier's green score.	AI Ethics
Supply Chain Data Quality	Antecedent	Accuracy, integrity, and representativeness of vendor emissions data.	Information Systems; Agency Theory
Green FinTech Governance Controls	Antecedent	Green governance controls: policies, testing, and human oversight structures.	Agency Theory
Human Ethical Judgment	Mediator	Human moral reasoning in relation to automated green finance recommendations.	Environmental Ethics; Agency Theory

Upstream Stakeholder Trust	Mediator	Upstream vendor and investor trust in the fairness of green finance.	Stakeholder Theory
Green Financial Decision Quality	Outcome	Risk-appropriate, fair, and effective distribution of sustainable capital.	Agency Theory
Substantive ESG Compliance	Outcome	Carbon emission reduction and waste reduction in the supply chain.	Stakeholder Theory; ESG Governance
Reduced Integrity Risk	Outcome	Lower likelihood of greenwashing litigation and regulatory fines.	Agency Theory; Corporate Governance
Board Green-Tech Competence	Moderator	Technical and sustainability literacy of directors and executives.	Agency Theory
Regulatory Environment Stringency	Moderator	Strength of climate and AI laws and how they are enforced.	Institutional Theory

As seen in the table, each construct has corresponding theory or theories that support it, thus again providing the basis that there is no single theory that is able to explain Governance in algorithmic green finance. Constructs with multiple sources support their conceptual basis more strongly than constructs with only one source. The constructs are also phrased at a level of abstraction that enables their empirical testing using existing instruments that can measure them, such as

multidimensional instruments for measuring data quality or validated instruments for measuring trust, as suggested in Section 9.

7. Theoretical Contributions

This paper makes three important contributions to the literature on corporate finance and sustainable operations:

- Empowering algorithms with human elements in green finance. It takes a humanistic perspective to algorithmic green finance, paying attention to the design of algorithms, the flow of data, and the monitoring and management of algorithms
- Leveraging AI to boost the FinTech industry.
- Process-oriented ESG integrity. It is a paradigm change from a product-based reporting to a fully integrated approach, which gives substance to the concept of value of transparency and Governance in the process Of moving towards sustainability.

The contributions go beyond Green FinTech. The framework further addresses the governance of ethical use of AI in corporate financial decision making in the context of green supply chain finance, and thus exemplifies how agency relationships can be mediated through non-human decision-making systems. It offers a framework for critically examining other domains where algorithms are used to allocate limited resources, such as automated lending, procurement and underwriting of insurance. This process-based approach also proposes metrics to measure corporate integrity prior to the publication of reported ESG results, thus allowing the determination of corporate integrity in real time before the results are reported.

8. Management and Policy Implications

For Corporate Executives and CFOs: Green FinTech algorithms are not just IT efficiency devices, but important financial instruments that should be managed with the same seriousness as any other, should be regularly audited and should have strong governance by humans in the loop. Couple financial incentive (such as preferential discounting) with capacity building and technical support to enable tier-2 and tier-3 suppliers, who are resource constrained, to upgrade their carbon tracking system without financial exclusion. For Policymakers and Regulators: Regulation should extend beyond voluntary disclosure guidelines and set transparency and data verification requirements for AI sustainability platforms, to ensure consistency and fairness around the world. For Investors and ESG Rating Providers: Investors should seek the methodologies and governance frameworks behind supply chain sustainability scores, rather than only the scores, and should be aware that even if two scores are the same, methodological differences could be present, which may be hidden in the dark if not transparent ([Berg et al., 2022](#)). Suppliers should invest in data documentation and verification capabilities and look for formal procedures to challenge or appeal assessments made by algorithms that are not aligned with their environmental performance.

9. Future Research Agenda

The findings suggest that future green supply chain finance platforms are likely to rely on ESG Digital Twins, which appear to provide virtual representations of supplier sustainability performance that could be continuously updated through environmental, operational, and financial data streams. However, these digital twins may enable real-time sustainability assessment, dynamic financing adjustments, scenario simulation, and predictive risk monitoring. Moreover, the evidence indicates that by reducing dependence on retrospective reporting, ESG Digital Twins might significantly reduce opportunities for greenwashing while improving financing allocation

accuracy. Furthermore, the results demonstrate that this study extends current scholarship by recognizing that future green supply chain finance systems could evolve from decision-support tools into partially autonomous decision-making ecosystems. Digital twins show governance shifts from controlling outputs to governing adaptive systems. Nevertheless, the analysis suggests that in such environments, the important governance shifts from controlling individual algorithmic outputs to governing adaptive socio-technical systems that appear to be composed of AI agents, financial platforms, digital verification technologies, and multi-stakeholder oversight mechanisms. Additionally, the study may advance sustainable finance scholarship by proposing Adaptive Algorithmic Stewardship as a future-oriented governance paradigm for AI-enabled green supply chain finance. Given that conventional frameworks show limitations, the findings could indicate that moving beyond conventional transparency and explainability frameworks, the model integrates auditability, digital trust, resilience, inclusion, and responsible AI capabilities into a unified governance architecture. Furthermore, the framework might provide a foundation for governing next-generation sustainable finance ecosystems that appear to be characterized by autonomous decision-making, real-time sustainability verification, and evolving regulatory expectations. Framework establishes foundation for ecosystems characterized by autonomous decision-making.

The propositions should be tested empirically in the future with multi-method approaches like structural equation modelling (SEM) based on cross-industry survey data from corporate finance. The framework also abstracts away from the technical features Of the Green FinTech tools implemented spanning from a rule-based carbon calculator to a complex machine learning model and could impact the applicability of certain constructs. Finally, the analysis is based on a buyer led and governance perspective, ignoring supplier led and platform-led governance models.

10. Conclusion

The rising convergence of Green FinTech, artificial intelligence and sustainable supply chain finance offers new opportunities for linking financial incentives to environmental goals. However, the success of these technologies goes beyond their technical merits to the sets of governance mechanisms that inform the design, implementation and accountability of these technologies. This paper contributes a conceptual framework of algorithmic stewardship that extends agency theory, stakeholder theory, environmental ethics and AI governance principles to explain how transparent, explainable and auditable algorithmic systems can make a difference to meaningful sustainability outcomes.

We show that carbon data transparency, algorithmic explainability, supply chain data quality and governance controls are foundational drivers of responsible green financing. Their impact on organizational outcomes are mediated by two mechanisms: human ethical judgment and stakeholder trust. These two mechanisms collectively lead to higher quality financing decisions, substantive ESG compliance, reduced integrity risks and improved supply chain resiliency. Finally, we show that organizational capabilities and regulatory environments are also important determinants of algorithmic governance effectiveness.

Our study makes two distinct contributions to the literature. First, we extend traditional governance theories for technology ecosystems to AI-enabled financial ecosystems. Second, we contribute algorithmic stewardship as a governance paradigm for sustainable finance. Rather than being autonomous decision makers, we conceptualize algorithms as tools that need continuous human

accountability, ethical oversight and institutional control. This also redirects scholarly focus from technology adoption to responsible technology governance.

Organizations should establish that transparency, auditability, fairness safeguards, and human oversight are important elements in green financing platforms to demonstrate that sustainability-linked financial decisions appear both effective and legitimate. However, policymakers and regulators may need to establish that standards for algorithmic accountability, ESG data verification, and stakeholder protection are critical. Moreover, the concept of algorithmic stewardship could provide that a key foundation appears relevant for balancing innovation, integrity, and sustainability as digital sustainability ecosystems might continue to demonstrate greater autonomy in future green supply chain finance systems. Furthermore, the ability of organizations to govern algorithms responsibly may indicate that sustainable financial transformation could depend on this critical capacity rather than on algorithms alone. Systems show future green supply chain finance requires combining technological intelligence with ethical accountability, stakeholder trust, and institutional stewardship.

References

- Arrieta, A. B., Diaz-Rodríguez, N., Del Ser, J., Bennetot, A., Tabik, S., Barbado, A., Garcia, S., Gil-Lopez, S., Molina, D., Benjamins, R., Chatila, R., & Herrera, F. (2020). Explainable artificial intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI. *Information Fusion*, 58, 82–115. <https://doi.org/10.1016/j.inffus.2019.12.012>
- Barocas, S., & Selbst, A. D. (2016). Big data's disparate impact. *California Law Review*, 104(3), 671–732. <https://doi.org/10.15779/Z38BG31>
- Berg, F., Kölbel, J. F., & Rigobon, R. (2022). Aggregate confusion: The divergence of ESG ratings. *Review of Finance*, 26(6), 1315–1344. <https://doi.org/10.1093/rof/rfac033>
- Binns, R. (2018). Fairness in machine learning: Lessons from political philosophy. *Proceedings of Machine Learning Research*, 81, 149–159. <https://proceedings.mlr.press/v81/binns18a.html>
- Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. *California Management Review*, 54(1), 64–87. <https://doi.org/10.1525/cmr.2011.54.1.64>
- DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, 48(2), 147–160. <https://doi.org/10.2307/2095101>
- Donaldson, T., & Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. *Academy of Management Review*, 20(1), 65–91. <https://doi.org/10.5465/amr.1995.9503271992>
- Eisenhardt, K. M. (1989). Agency theory: An assessment and review. *Academy of Management Review*, 14(1), 57–74. <https://doi.org/10.5465/amr.1989.4279003>

Floridi, L., & Cowls, J. (2019). A unified framework of five principles for AI in society. *Harvard Data Science Review*, 1(1). <https://doi.org/10.1162/99608f92.8cd550d1>

Floridi, L., Cowls, J., Beltrametti, M., Chatila, R., Chazerand, P., Dignum, V., Luetge, C., Madelin, R., Pagallo, U., Rossi, F., Schafer, B., Valcke, P., & Vayena, E. (2018). AI4People—an ethical framework for a good AI society: Opportunities, risks, principles, and recommendations. *Minds and Machines*, 28(4), 689–707. <https://doi.org/10.1007/s11023-018-9482-5>

Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.

Gelsomino, L. M., Mangiaracina, R., Perego, A., & Tumino, A. (2016). Supply chain finance: A literature review. *International Journal of Physical Distribution & Logistics Management*, 46(4), 348–366. <https://doi.org/10.1108/IJPDLM-08-2014-0173>

Gomber, P., Koch, J.-A., & Siering, M. (2017). Digital finance and FinTech: Current research and future research directions. *Journal of Business Economics*, 87(5), 537–580. <https://doi.org/10.1007/s11573-017-0852-x>

Jaakkola, E. (2020). Designing conceptual articles: Four approaches. *AMS Review*, 10(1–2), 18–26. <https://doi.org/10.1007/s13162-020-00161-0>

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4), 305–360. [https://doi.org/10.1016/0304-405X\(76\)90026-X](https://doi.org/10.1016/0304-405X(76)90026-X)

Jobin, A., Ienca, M., & Vayena, E. (2019). The global landscape of AI ethics guidelines. *Nature Machine Intelligence*, 1(9), 389–399. <https://doi.org/10.1038/s42256-019-0088-2>

Martin, K. (2019). Ethical implications and accountability of algorithms. *Journal of Business Ethics*, 160(4), 835–850. <https://doi.org/10.1007/s10551-018-3921-3>

Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An integrative model of organizational trust. *Academy of Management Review*, 20(3), 709–734. <https://doi.org/10.5465/amr.1995.9508080335>

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of Management Review*, 22(4), 853–886. <https://doi.org/10.5465/amr.1997.9711022105>

Mittelstadt, B. D., Allo, P., Taddeo, M., Wachter, S., & Floridi, L. (2016). The ethics of algorithms: Mapping the debate. *Big Data & Society*, 3(2), 1–21. <https://doi.org/10.1177/2053951716679679>

Rai, A. (2020). Explainable AI: From black box to glass box. *Journal of the Academy of Marketing Science*, 48(1), 137–141. <https://doi.org/10.1007/s11747-019-00710-5>

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, 16(15), 1699–1710. <https://doi.org/10.1016/j.jclepro.2008.04.020>

Wachter, S., Mittelstadt, B., & Russell, C. (2018). Counterfactual explanations without opening the black box: Automated decisions and the GDPR. *Harvard Journal of Law & Technology*, 31(2), 841–887.

Wang, R. Y., & Strong, D. M. (1996). Beyond accuracy: What data quality means to data consumers? *Journal of Management Information Systems*, 12(4), 5–33. <https://doi.org/10.1080/07421222.1996.11518099>

Schwendner, P., & Posth, J. A. (2024). Editorial: Trends in AI4ESG: AI for sustainable finance and ESG technology. *Frontiers in Artificial Intelligence*, 7. <https://doi.org/10.3389/frai.2024.1448045>

Gregor, S. (2024). Responsible artificial intelligence and journal publishing. *Journal of the Association for Information Systems*, 25(1), 48-60. <https://doi.org/10.17705/1jais.00863>

Lee, J., & Shin, D. (2024). AI governance in a complex and rapidly changing regulatory environment. *Humanities and Social sciences communications*, 11 <https://doi.org/10.1057/s41599-024-03560-x>

Batool, A., Zowghi, D., & Bano, M. (2024). Responsible AI governance: A systematic literature review. *Proceedings of ICSE 2024 Workshop on Responsible AI Engineering*. Available at: <https://arxiv.org/abs/2401.10896>

Trienens, M., Rasor, R., Kharatyan, A., Dumitrescu, R., & Anacker, H. (2024). Digital twins to increase sustainability throughout the system life cycle: A systematic literature review. *Proceedings of the Design Society*, 4, 2277-2286. <https://doi.org/10.1017/pds.2024.230>

Ciobanu, E. (2025). The future of ESG in multinationals: How digital twin technologies enable strategic value creation. *Systems*, 13(12), 1121. <https://doi.org/10.3390/systems13121121>

Alotaibi, E. M., Khallaf, A., Abdallah, A. A.-N., Zoubi, T., & Alnesafi, A. (2024). Blockchain-driven carbon accountability in supply chains. *Sustainability*, 16(24), 10872. <https://doi.org/10.3390/su162410872>

Almadadha, R. (2024). Blockchain technology in financial accounting: Enhancing transparency, security, and ESG reporting. *Blockchains*, 2(3), 312-333 <https://doi.org/10.3390/blockchains2030015>

Mofatteh, M. Y., Davallou, R., Ishimwe, C. N., Divekar, S. S., & Valilai, O. F. (2024). Developing a blockchain based supply chain CO₂ footprint tracking framework enabled by IoT. *International*

Journal of Advanced Computer Science and Applications, 15(10).
<https://doi.org/10.14569/IJACSA.2024.0151002>

Patro, P. K., Jayaraman, R., Acquaye, A., Salah, K., & Musamih, A. (2025). Blockchain-based solution to enhance carbon footprint traceability, accounting, and offsetting in the passenger aviation industry. *International Journal of Production Research*, 63(22), 8235-8268.
<https://doi.org/10.1080/00207543.2024.2441450>

Wu, H., Liu, J., & Liang, B. (2024). AI-driven supply chain transformation in Industry 5.0: Enhancing resilience and sustainability. *Journal of the Knowledge Economy*.
<https://doi.org/10.1007/s13132-024-01999-6>

Riad, M., Naimi, M., & Okar, C. (2024). Enhancing supply chain resilience through artificial intelligence: Developing a comprehensive conceptual framework for AI implementation and supply chain optimization. *Logistics*, 8(4), 111. <https://doi.org/10.3390/logistics8040111>

Smyth, C., Dennehy, D., Wamba, S. F., Scott, M., & Harfouche, A. (2024). Artificial intelligence and prescriptive analytics for supply chain resilience: A systematic literature review and research agenda. *International Journal of Production Research*, 62(23), 8537-8561.
<https://doi.org/10.1080/00207543.2024.2341415>

Suresh, K. S. (2024). Enhancing supply chain resilience through artificial intelligence: A strategic framework for executives. *Emerging Science Journal*, 8(4). <https://doi.org/10.28991/ESJ-2024-08-04-013>

Singh, G., Kaur, S., Bhullar, P. S., Kaur, K., Bhandari, R., & Singh, G. (2024). Mapping the nexus between artificial intelligence (AI) in sustainable finance and environmental social governance (ESG): A bibliometric analysis. Available at: https://www.jisem-journal.com/download/22_AI_SF_ESG.pdf

Hu D, Gan C,(2025).Green finance development and its origin, motives and barriers: an exploratory study [10.1007/s10668-024-05570-w](https://doi.org/10.1007/s10668-024-05570-w)