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Algorithmic-Age Green Trade Governance: AI Empowerment, Institutional Transformation, and Legitimacy Reconstruction

Zijun ZHOU
Business School, Qilu Institute of Technology, Jinan 250200, China

Abstract

Green trade standards face a persistent governance trilemma of efficiency, equity, and legitimacy. Current frameworks are inefficient due to high monitoring costs, inequitable because they impose hidden barriers on developing countries, and suffer legitimacy deficits as unilateral measures challenge WTO rules. This paper explores how Artificial Intelligence (AI) can reshape this paradigm. Rather than offering a utopian fix, AI empowers governance through three mechanisms: cognitive empowerment, transparency and verification, and capacity building. A theoretical framework of "AI-enabled green trade governance" is proposed, drawing on global value chain governance, institutional embeddedness, and socio-technical transition theory. Evidence from the EU's CBAM transitional period, blockchain-based traceability models, and agent-based negotiation simulations illustrates AI's practical potential. The study argues that AI is driving a legitimacy shift from legal-procedural to techno-scientific foundations and calls for inclusive governance frameworks to ensure that digital tools enhance both fairness and effectiveness in global green trade.

Keywords Artificial Intelligence; Green Trade; Trade Standards; Global Governance; Technological Empowerment; Governance Trilemma; WTO

1 Introduction: The Trilemma of Green Trade Governance

1.1 The Rise and Contradictions of the Green Trade Paradigm

Global environmental crises, including climate change, biodiversity loss, and resource depletion, are reshaping international relations and the global economic landscape with unprecedented depth and breadth. Against this backdrop, the concept of "sustainable development" has evolved from a marginal policy initiative into a core principle of international law and global governance, demanding a balance between economic development, social progress, and environmental protection. As the central nervous system of global economic activity, international trade is an indispensable arena for achieving sustainable development goals. Consequently, a new "green trade" paradigm is emerging, one that emphasizes the harmonization of trade activities with environmental protection and even utilizes trade policy as a tool to advance global environmental governance. From the global emissions reduction commitments in the

Paris Agreement to the proliferation of trade measures in Multilateral Environmental Agreements (MEAs), environmental considerations are being deeply embedded into the fabric of international trade rules.

However, the rise of the green trade paradigm is accompanied by a fundamental governance dilemma: how to draw a clear line between promoting legitimate environmental objectives and enabling new forms of trade protectionism. Green trade standards—such as product life-cycle assessments (LCA), eco-labels, and carbon footprint accounting—are the core instruments for achieving these environmental goals. Yet, their technical complexity and regulatory nature make them susceptible to misuse. When these standards, particularly those unilaterally designed and implemented by developed economies, are applied to international trade, they can easily morph into "Green Trade Barriers." By imposing stringent technical, informational, and compliance requirements, these barriers create significant obstacles for exports from developing countries, eroding their comparative advantages and igniting fierce debates over "green protectionism". This conflict is not merely one of economic interests but a contest over normative power in global governance.

1.2 Deconstructing the Governance Trilemma

This paper conceptualizes this core dilemma as an intractable "trilemma": the simultaneous pursuit of efficiency, equity, and legitimacy in green trade governance often results in a zero-sum game, where strengthening one objective comes at the expense of the others. This trilemma is not a static problem but a dynamic, self-reinforcing cycle of failure. A unilateral measure like the EU's Carbon Border Adjustment Mechanism (CBAM) may be adopted to enhance the legitimacy of a domestic climate policy. However, its complex reporting requirements create an efficiency deficit through high compliance costs. These costs disproportionately harm producers in developing countries, exacerbating the equity deficit. This perceived inequity, in turn, circles back to undermine the measure's legitimacy within the multilateral framework of the World Trade Organization (WTO). This cyclical pathology means that any solution targeting only one deficit is likely to fail, making a systemic intervention necessary.

The trilemma's components are as follows:

Efficiency Deficit: This deficit stems from severe information asymmetries and prohibitive transaction costs. The effective implementation of green standards depends on the accurate and reliable measurement of a product's environmental performance. In practice, however, a product's true environmental impact across its lifecycle is complex and difficult to observe directly. Conducting a comprehensive LCA is not only expensive and time-consuming but its reliability is often contested. Furthermore, third-party certification and auditing mechanisms constitute significant transaction costs, especially for small and medium-sized enterprises (SMEs). Consumers, faced with limited information and a proliferation of labels, struggle to distinguish credible claims from "greenwashing," which erodes market signaling efficiency.

Equity Deficit: This deficit manifests in the structural inequality between developed nations (the "Global North") and developing nations (the "Global South"). The power to set green standards is often concentrated in the North, with standards reflecting their technological capabilities and environmental preferences while failing to consider the developmental stage and capacity constraints of the South. Consequently, these "one-size-fits-all" international standards often function as technical barriers to trade (TBTs) for Southern exporters, undermining their comparative advantages in labor-intensive industries. Moreover, green standards can be wielded as strategic trade policy tools—a form of "green protectionism"—whereby developed countries protect their domestic markets by setting standards that their own industries can meet but which are out of reach for foreign competitors.

Legitimacy Deficit: This deficit arises from the tension between green trade measures and the multilateral trading system centered on the WTO. The WTO's legal framework, built on core principles like non-discrimination, is challenged by unilateral green measures with extraterritorial effects. While Article XX of the General Agreement on Tariffs and Trade (GATT) provides exceptions for environmental protection, the interpretation of these clauses remains one of the most contentious areas in WTO dispute settlement. The EU's CBAM has brought this legitimacy conflict to a head. Although intended to prevent "carbon leakage," many trading partners, particularly developing nations, question whether its complex reporting and verification requirements constitute a disguised and discriminatory trade barrier, thereby challenging its legitimacy under WTO law.

1.3 AI as a Catalyst for Governance Reconfiguration

As this trilemma intensifies, Artificial Intelligence (AI) emerges as a powerful catalyst for change. As the engine of the Fourth Industrial Revolution, AI's capacity for data processing, pattern recognition, and decision optimization is profoundly altering the operation of international trade. Its disruptive potential extends far beyond commercial efficiency, posing unprecedented challenges to existing global economic governance frameworks. The "black box" nature of algorithms challenges the transparency principles of trade rules; the globalization of data flows clashes with the rise of data sovereignty; and AI-driven decision-making blurs the lines between state measures and private actions. AI is therefore not merely a technical tool but a disruptive governance technology reconfiguring power relations.

1.4 Research Question and Contributions

Given the inherent trilemma of green trade standards and the disruptive potential of AI, this paper poses the central research question: How, and under what governance conditions, can AI empower the creation of more efficient, equitable, and legitimate green trade standards?.

The core argument of this paper is that AI is catalyzing a profound governance paradigm shift: from a traditional model based on "legal-procedural legitimacy," which relies on the interpretation of legal texts and procedural justice, to an emerging model of "techno-scientific legitimacy," which depends on the perceived reliability of data and the effectiveness of algorithms. This paper makes the following academic and policy contributions:

Theoretically, this paper develops a novel "dual-legitimacy" framework, arguing that AI is forcing a shift from purely legal-procedural legitimacy to a hybrid model that must incorporate and balance techno-scientific claims of accuracy and objectivity. It constructs an original analytical framework of three AI empowerment mechanisms (Cognitive, Transparency & Verification, Capacity-Building) and systematically embeds them in a dialogue with mainstream global governance theories, including Global Value Chain (GVC) governance, Institutional Embeddedness, and the Multi-Level Perspective (MLP) on socio-technical transitions.

Empirically, it provides a verifiable evidence base for these mechanisms through a multi-method analysis of the EU's CBAM transitional period, the transferability of blockchain-based traceability models, and the application of Agent-Based Modeling (ABM) to trade negotiations.

In terms of policy innovation, it proposes a proactive governance architecture for the algorithmic age, introducing an "algorithmic weaponization toolbox" and a "capability stepladder model" to address emerging challenges and promote inclusive adoption.

2 Theoretical Foundations: Situating AI in Global Governance Theory

To establish a rigorous theoretical foundation, this section situates the paper's framework of AI's empowerment mechanisms within established theories of international political economy and technology governance. By engaging with theories of GVC governance, institutional embeddedness, and the MLP of socio-technical transitions, this analysis reveals AI not merely as a technical instrument but as a profound force that reconfigures power structures, alters institutional forms, and drives systemic paradigm shifts. These theoretical lenses are not treated as separate conversations but as a nested, multi-scalar framework describing the same phenomenon at different levels of analysis. AI acts as a niche innovation at the macro level (MLP) precisely because its institutional embeddedness at the meso level (Granovetter) grants it the power to reconfigure GVCs at the micro level (Gereffi).

2.1 AI as a GVC Reconfiguration Force: From Buyer-Driven to Computational Governance

GVC theory, pioneered by scholars like Gary Gereffi, provides a powerful framework for understanding how global production is organized and governed. The theory identifies "lead firms" that coordinate and control production networks through various governance models. AI's intervention is fundamentally altering these power dynamics.

First, AI is fostering a new GVC modality where "platform firms"—tech giants that control core algorithms and vast datasets—are emerging as the new lead firms. This aligns with analyses of platform capitalism, which observe the concentration of power and value capture in a few "Big Tech" actors. In the GVCs for green trade, the traditional leadership role played by large retailers or brands (e.g., Walmart) may be supplemented or supplanted by companies providing AI-driven compliance and certification platforms (e.g., Google, Microsoft, or specialized startups). By offering "one-stop" solutions for everything from carbon footprinting to supply chain traceability, these platforms embed themselves at critical nodes, granting them immense power to define standards and set the rules of participation.

Second, AI is transforming the mode of GVC governance itself. Traditional governance relies on contracts, audits, and certifications to enforce standards set by lead firms. AI-enabled governance, by contrast, shifts toward "computational governance" based on real-time data streams and automated decision-making. An AI system can automatically adjudicate compliance based on data from Internet of Things (IoT) sensors and trigger a smart contract to issue a certificate. While seemingly objective, this model encodes governance power into the algorithm itself, making its design and the data it is trained on new arenas of power contestation. This represents a fundamental shift from governance based on human and institutional trust to governance based on machine trust.

2.2 The Institutional Embeddedness of Algorithms: When Code Becomes Rule

The theory of institutional embeddedness, famously articulated by Mark Granovetter, posits that economic actions are not isolated but are deeply embedded within social, political, and institutional structures. New technologies are not simply "applied" to existing structures; they interact with and ultimately become part of them.

When a trade standard is implemented via an AI algorithm, it undergoes an ontological transformation. Traditional legal rules, such as WTO treaty texts, are "ostensive"—they exist as text and require interpretation and performative execution by human actors like judges and officials. However, when these rules are encoded into an algorithm, they acquire a "material aspect". An AI model that calculates a product's carbon footprint is not a description of the rule; its mathematical formulas and data-processing pathways are the rule in its tangible, executable form.

This "technical embeddedness" has profound consequences. It shifts governance from a domain of interpretation to one of computation. The ambiguity of legal text allows for flexible application and evolution through judicial review. The logic of an algorithm, however, is precise and rigid, executing rules automatically and reducing the space for human discretion. This changes how institutions evolve and are contested. Challenging an unfair legal provision requires legal argument and political negotiation; challenging a biased algorithm requires data science expertise and the capacity for reverse-engineering "black box" models. AI, therefore, does more than just embed itself in existing institutions; it changes their very logic of operation, creating a "socio-technical system" where law and code co-produce governance.

2.3 AI as a Niche Disruptor: A Socio-Technical Transition Perspective (MLP)

The MLP framework, developed by scholars like Frank Geels, offers a powerful tool for analyzing how societies transition from one dominant socio-technical system to another. It posits that such transformations result from the interaction of three analytical levels: the macro-level "landscape," the stable "socio-technical regime," and the innovative "niche". This framework can be used to analyze the reconfiguration of green trade governance:

Landscape: This level represents broad, exogenous pressures beyond the control of individual actors. In this context, these pressures include the escalating climate crisis, shifts in the global economic order, and the pervasive digital transformation, which fuels geopolitical "techno-nationalism". These landscape pressures combine to challenge and destabilize the existing governance model.

Socio-technical Regime: This is the dominant and stable network of rules, practices, and actors. In green trade, the regime is the WTO-centric system, characterized by legal texts, multilateral negotiations, and third-party certification. Its legitimacy is founded on "legal-procedural" principles of political negotiation and legal interpretation. While stable, this regime's capacity to respond effectively to landscape pressures is increasingly questioned, as evidenced by negotiation deadlocks and the rise of unilateralism.

Niche: This level is the protected space where radical innovations can develop without immediate pressure from the dominant regime. AI-driven governance solutions, such as intelligent CBAM systems and dynamic green labels, are emerging from such niches. These innovations promise a new basis for legitimacy—"techno-scientific legitimacy"—by offering more precise data and efficient algorithms to solve the trust and efficiency problems that plague the current regime.

A systemic transition occurs through the dynamic interplay of these three levels. Landscape pressures can create "windows of opportunity" that weaken the incumbent regime's stability. At such moments, mature niche innovations can gain traction, form alliances with reform-minded actors within the regime, and challenge existing rules, potentially triggering a system-wide transformation. The MLP framework thus reveals that AI's disruptive potential is not guaranteed by its technical superiority alone; its success depends on its ability to offer a more compelling solution to macro-level pressures than the existing regime can provide.

2.4 Where We Move the Literature: Three Propositions

This section crystallizes the paper's theoretical contributions in the form of three distinct propositions that emerge from the preceding dialogue with global governance theories.

Proposition 1: From Contract to Computation. AI-driven systems transform GVC governance from a model based on contractual obligations and third-party audits to one of "computational governance," where compliance is automatically verified against real-time data, shifting power from lead buyers to platform orchestrators.

Proposition 2: The Dual-Wheel of Legitimacy. The institutionalization of AI in trade governance forces a shift in the basis of legitimacy from a singular reliance on legal-procedural correctness to a "dual-wheel" model that must balance procedural norms with techno-scientific claims of accuracy, efficiency, and objectivity.

Proposition 3: The Non-Linearity of Equity. In the context of developing economies, the impact of AI on trade equity is non-linear and follows a U-shaped curve. Initial adoption increases barriers due to high costs and capability gaps, but beyond a certain threshold of institutional and technical capacity-building, AI can significantly lower compliance costs and enhance market access, thereby reducing inequity.

3 AI's Empowerment Mechanisms and Evidentiary Cases

Building on the theoretical foundation, this section operationalizes the paper's core framework by detailing the three AI empowerment mechanisms and grounding them in verifiable evidence. Each mechanism is accompanied by a quantitative indicator to enhance its verifiability, and the case studies are supported by new empirical data and structured tables to demonstrate their real-world applicability.

3.1 Mechanism 1: Cognitive Empowerment

This mechanism enhances the scientific basis and dynamic adaptability of standards by enabling the analysis of vast, heterogeneous environmental data. AI models can process and fuse satellite imagery, IoT sensor data, and climate models to assess environmental impacts with a granularity that far exceeds human capabilities. This provides a dynamic, evidence-based foundation for standards, making them more scientifically robust and less susceptible to claims of being arbitrary trade barriers, thereby directly addressing the legitimacy deficit. A key quantitative indicator for this mechanism is the False Positive/Negative Rate in detecting environmental non-compliance. For example, AI models analyzing satellite imagery to detect illegal deforestation or monitoring industrial emissions can be benchmarked for accuracy, with metrics like precision, recall, and F1-score providing a clear measure of their effectiveness compared to traditional methods[5].

3.2 Mechanism 2: Transparency and Verification Empowerment

This mechanism leverages the synergy of AI, IoT, and Blockchain to create a transparent, traceable, and tamper-proof supply chain monitoring system, thereby "automating trust". IoT sensors capture real-time environmental data (e.g., energy consumption), which is recorded on an immutable blockchain ledger. AI then acts as a "smart auditor," continuously analyzing this data to verify compliance and trigger smart contracts that can, for example, automatically issue a digital green certificate. This process directly tackles the efficiency deficit by replacing costly third-party audits with machine trust. A relevant quantitative indicator is the MRV Cost per Unit (e.g., per ton of CO_2e or per certified product). While digital MRV systems have high initial implementation costs, they promise significant long-term savings. For instance, studies of forest carbon projects estimate traditional MRV costs can range from \$0.15 to \$1.40 per ton, comprising up to 20% of the credit's total cost—a figure that technology aims to drastically reduce[7].

3.3 Mechanism 3: Capacity-Building Empowerment

This mechanism addresses the equity deficit by "democratizing compliance" through low-cost, intelligent, and personalized digital tools. AI-driven "Compliance-as-a-Service" platforms can act as virtual consultants for SMEs in developing countries, helping them navigate complex regulations like CBAM by automatically generating reports and suggesting cost-effective green upgrades. This lowers the barrier to entry into global green supply chains. A critical quantitative indicator is the SME Adoption Rate of Digital/AI Compliance Tools. Data shows a significant "capability gap" that these tools aim to close. In the EU, SME adoption of sophisticated technologies like enterprise resource planning (ERP) or data analytics lags far behind that of large enterprises[9]. In the US, while the trend is positive, with approximately 69% of SMEs having adopted advanced digital tools, a gap remains, grounding the "digital divide" argument in concrete numbers[10].

3.4 Case Studies with Enhanced Evidence

3.4.1 Case 1: An Intelligent Carbon Border Adjustment Mechanism (i-CBAM)

The practical challenges encountered during the CBAM transitional period (October 1, 2023, to December 31, 2025) starkly illustrate the "efficiency deficit" and underscore the need for an AI-driven solution. During this phase, importers are required to submit quarterly reports on the embedded emissions of their goods without yet facing financial penalties, creating a real-world experiment in cross-border environmental data collection[12]. The evidence from this period, summarized in Table 1, provides a compelling justification for an "intelligent" CBAM (i-CBAM) that could use AI to automate data verification, conduct risk-based assessments, and lower compliance burdens (Table 1).

Table 1: Verifiable Indicators of the EU CBAM's Transitional Period Challenges

Challenge Dimension	Quantitative/ Qualitative Indicator	Finding & Source
Data Acquisition	Difficulty in obtaining supplier data	Official EU guidance acknowledges that "many suppliers lack the technical means... and in some cases, there seems to be an unwillingness to cooperate." The complexity is magnified for multi-tiered supply chains where importers lack direct contact with producers[13].
Compliance Costs	Cost per report; Economic Impact	Industry reports indicate high costs for external expertise to prepare CBAM reports, potentially reaching tens of thousands of dollars per report. An impact assessment for Vietnam estimated that CBAM could reduce steel exports to the EU by 50% ($1.1 billion) and raise final product prices by 15–40% for steel and aluminum[14].
Administrative & Technical Barriers	Submission delays; System functionality	The European Commission officially acknowledged "technical issues" with the CBAM Transitional Registry, which prevented some businesses from submitting their first reports on time. A "request delayed submission" function was introduced, granting an additional 30-day extension[15].

3.4.2 Case 2: Blockchain and Dynamic Green Labels

The concept of a "dynamic green label"—a digital product passport that provides real-time, verifiable data on a product's environmental footprint—may seem futuristic. However, its core technical and business logic has already been proven through mature commercial applications in food supply chain traceability. Projects like the Walmart-IBM Food Trust demonstrate that combining IoT, blockchain, and mobile scanning to track goods through complex global supply chains is not only feasible but also delivers significant efficiency gains. For example, the system reduced the time to trace a package of mangoes from its farm of origin from nearly 7 days to 2.2 seconds. Table 2 illustrates the direct transferability of these components from food safety to green trade verification (Table 2).

Table 2: Transferability of Blockchain Traceability from Food Safety to Green Trade

Core Component	Application in Food Traceability (e.g., Walmart Food Trust)	Transferable Application in Green Trade
Digital Identity	A QR code on a mango package links to its farm of origin, harvest date, and shipping details.	A QR code on a garment links to its digital product passport, detailing the origin of the cotton, water usage in dyeing, and energy source for manufacturing.
Data Capture (IoT)	IoT sensors monitor and record the temperature and humidity of a shipping container in real-time to ensure cold chain integrity.	Smart meters monitor and record the energy consumption (kWh) and water usage (m^3) at the production facility, distinguishing between renewable and fossil fuel sources.
Immutable Record (Blockchain)	A shared, tamper-proof ledger records every transaction and movement of the product from farm to store, creating a single source of truth for all stakeholders[16].	A shared ledger records the product's lifecycle carbon footprint, from raw material extraction and processing to final assembly and shipping, creating a verifiable audit trail.
Automated Verification (Smart Contract)	A smart contract could automatically trigger payment to a supplier upon confirmed delivery of goods that have remained within specified temperature parameters throughout transit.	A smart contract automatically issues a digital "Green Certificate" or grants market access once the product's cumulative carbon footprint is verified to be below the required regulatory threshold.

3.4.3 Case 3: Agent-Based Modeling (ABM) for Negotiations

ABM offers a powerful "policy laboratory" to simulate the complex dynamics of international negotiations over green trade standards. Unlike traditional economic models that often assume rational actors and equilibrium outcomes, ABM can model the behavior of heterogeneous agents (e.g., countries with different economic interests and technological capabilities) and capture emergent, non-linear system dynamics. This method has been successfully applied to analyze climate change negotiations, demonstrating its potential for assessing the distributional impacts of different policy proposals and identifying fairer, more inclusive solutions. A crucial component of robust ABM is sensitivity analysis, which systematically tests how variations in model parameters and assumptions affect the outcomes[19]. This ensures that the model's conclusions are not artifacts of arbitrary parameter choices. For instance, a sensitivity analysis could plot the "Level of Global Cooperation" (outcome) against varying levels of "Sanction Severity for Non-Compliance" and "Cost of Green Technology" (input parameters), revealing critical policy thresholds and trade-offs. To ensure the replicability of such an approach, a detailed description of the model's parameters and logic is essential.

4 The Architecture of Algorithmic Governance: Challenges and Responses

The practical application of AI in green trade governance, while promising, gives rise to a new set of profound challenges. Navigating these challenges requires a proactive and sophisticated governance architecture. A critical dynamic is the co-evolutionary relationship between the regulatory tools needed to govern AI (the "demand" for governance, often driven by the Global North) and the institutional capacity required to implement and engage with those tools (the "supply" of governance capacity, particularly in the Global South). A regulatory tool like an "algorithmic passport" is ineffective if trading partners lack the institutional capacity to verify it. Conversely, capacity-building efforts are aimless without clear international standards to guide them. Therefore, these two elements—the toolbox and the stepladder—must be developed in tandem through a coordinated international effort.

4.1 The "Algorithmic Weaponization" Toolbox

The rise of "techno-nationalism"—where states link technological prowess to national security and economic advantage—creates the risk of "algorithmic weaponization". This refers to the use of seemingly neutral technical systems as disguised, next-generation trade barriers. A country could, for example, design a biased AI verification system that unfairly penalizes the production methods of its competitors or set impossibly high data quality standards as a pretext for restricting market access. This shifts trade disputes from the realm of legal interpretation to technical debate, a domain where developing countries are often at a structural disadvantage. To counter this, a new governance "toolbox" is required:

Algorithmic Audits: This refers to a formal, structured process for reviewing AI systems used in trade to ensure fairness, transparency, and robustness[21]. An audit would go beyond checking for code errors to assess the governance processes behind the system, the quality and potential biases of its training data, and the real-world impact of its outputs[21]. This mechanism provides a pathway for internal assurance for developers and external verification for regulators and trading partners[21].

Cross-Border Model Passports: This is a proposed standardized documentation framework that would accompany a commercial AI model across borders. Akin to a product's safety information, the passport would contain essential, non-proprietary information about the model's intended use, training data characteristics, performance metrics, and fairness assessments[23]. This would facilitate regulatory review and build trust without requiring the disclosure of sensitive source code in most instances, thus balancing trade secret protection with the need for regulatory oversight[23].

Evidence Disclosure Standards: The WTO and other international bodies must develop new standards defining what constitutes acceptable "evidence" in trade disputes involving AI systems. The focus must shift from debating the interpretation of legal text to establishing clear criteria for data provenance, model validation protocols, and the use of explainable AI (XAI) techniques to justify algorithmic decisions[24].

4.2 The "Capability Stepladder Model"

To ensure that the algorithmic age does not create a new, insurmountable digital trade barrier, a structured and supportive framework for inclusive technology adoption is needed. Drawing inspiration from capability maturity models, this paper proposes a "capability stepladder model" to guide developing economies in building the necessary capacity to participate fairly in AI-driven green trade[26]. This model outlines a phased approach for building institutional and technical readiness:

Level 1 (Foundational): Focus on establishing basic digital infrastructure (e.g., reliable internet access), promoting widespread data literacy, and creating national data governance policies that align with international best practices.

Level 2 (Adoption): Implement national programs, including subsidies and training, to encourage SME adoption of existing, off-the-shelf digital compliance tools and platforms.

Level 3 (Adaptation): Foster domestic technical expertise to adapt and customize open-source AI tools and models to the specific needs and contexts of local industries.

Level 4 (Regulation): Establish a national AI regulatory body or empower an existing agency with the expertise to conduct algorithmic audits, verify "model passports," and participate meaningfully in international standard-setting bodies.

Level 5 (Innovation): Cultivate a domestic AI research and development ecosystem capable of creating novel green technology and governance solutions, transitioning from being a technology-taker to a technology-maker.

5 Conclusion: Navigating the Institutional Transition

5.1 Academic Contribution Revisited

This research began by identifying the "efficiency-equity-legitimacy" trilemma that currently paralyzes green trade governance. The analysis has demonstrated that AI is not a simple technical solution but a catalyst for a fundamental institutional transition. The primary academic contribution of this paper is the development of a dual-legitimacy model to understand this shift. It argues that the basis of legitimacy in global trade governance is moving from a singular reliance on legal-procedural norms to a hybrid framework that must also incorporate and validate techno-scientific claims. A second key contribution is the conceptualization of computational governance, which describes the transformation of GVC oversight from a system based on contracts and human audits to one managed through code and automated data verification.

5.2 Policy Contribution Revisited

This analysis yields a clear, multi-level set of policy recommendations designed to navigate this institutional transition responsibly and inclusively.

For the World Trade Organization (WTO):

Establish a permanent Committee on Trade and AI to serve as a forum for regulatory dialogue and to build institutional expertise in addressing techno-scientific challenges. Reform the dispute settlement mechanism by creating a roster of independent technical experts or authorizing panels to commission third-party algorithmic audits to support their rulings. Initiate plurilateral negotiations on creating "safe harbors" for the cross-border flow of data specifically for environmental verification purposes, balancing transparency with data sovereignty concerns.

For National Governments:

Invest in AI governance capacity—including regulatory bodies and auditing expertise—not just in AI technology itself. Utilize "regulatory sandboxes" to pilot and co-develop new AI-driven trade technologies and the rules that govern them in a controlled environment. Proactively shape the next generation of Free Trade Agreements (FTAs) by including robust chapters on digital trade, data flows, algorithmic transparency, and technical cooperation.

For International Standards Organizations (e.g., ISO, IEEE):

Develop global technical standards for AI systems used in trade and supply chains. These standards are crucial for creating a common language for assessing transparency, fairness, and auditability, which will be the bedrock of trust in a techno-scientific governance paradigm.

5.3 Counterfactual Analysis: The Primacy of Procedure under Uncertainty

This paper's argument for a paradigm shift toward techno-scientific legitimacy is conditional, not deterministic. A crucial counterfactual must be considered: what happens when the conditions for techno-scientific legitimacy are not met? When data is unreliable, when models are unauditable "black boxes," or when access to auditing tools and expertise is profoundly unequal, the techno-scientific pillar of legitimacy collapses. In such scenarios of high uncertainty and opacity, the principles of legal-procedural legitimacy—such as transparency, due process, the precautionary principle, and non-discrimination—must reassert their primacy. Procedure becomes the essential safeguard against the arbitrary exercise of unaccountable technological power. This demonstrates that the future of green trade governance lies not in a wholesale replacement of one paradigm with another, but in a dynamic and context-aware balancing act between the two. The ultimate challenge is to build a system that can leverage the power of techno-scientific verification while preserving the fundamental protections of procedural justice.

Author Biography ZHOU Zijun, male, born in June 1985 in Jinan, Shandong Province. He is an Associate Professor at the Business School of Qilu Institute of Technology, holding a doctoral degree. His research focuses on business administration. Correspondence Address: No. 3028 Jingshi East Road, Jinan, Shandong Province, 250200, P.R. China. Email: tooderdy@163.com, https://orcid.org/0009-0003-3609-2971.

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(Editor: Xin HUANG tooderdy@163.com)