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Leading the Twin Transition: A Socio-Technical Framework for Green Digital Trade under Global Carbon Constraints

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Abstract

Moving beyond the static "enabling-rebound" framework, this paper introduces Socio-Technical Transition (STT) theory and its Multi-Level Perspective (MLP) to conceptualize green digital trade as a dynamic system linking data governance and the trade regime. We identify the European Union's Carbon Border Adjustment Mechanism (CBAM) as a "landscape shock" that destabilizes the incumbent, carbon-intensive trade "regime" by pricing embedded carbon at the border. In response, we propose "Digital Carbon Competitiveness" (DCC)—a firm's dynamic capability to measure, manage, verify, and valorize carbon emissions using digital tools—as the critical "niche lever" for scaling innovation. Based on this, we outline a multi-level governance design (micro-niche incubation, meso-regime reformation, macro-rule shaping) and derive a set of testable propositions on how the interaction between CBAM and DCC affects emissions and competitiveness. The paper's contributions are threefold: (1) extending MLP theory to the under-researched domain of international trade; (2) conceptualizing and operationalizing DCC; and (3) proposing an integrated governance pathway for shaping the "twin transition."

Keywords Green Digital Trade; Twin Transition; Socio-Technical Transition; Multi-Level Perspective (MLP); Digital Carbon Competitiveness

1 Introduction: The Imperative of the Twin Transition

As we advance into the third decade of the 21st century, human society confronts two parallel and profoundly intertwined structural transformations: the low-carbon transition, centered on combating climate change, and the digital transition, driven by digital technologies. The confluence of these mega-trends constitutes the core governance challenge and developmental opportunity of our time, often termed the "twin transition"[1]. Successfully navigating this transition is not merely a matter of future national economic competitiveness; it is fundamental to the sustainable continuity of human society.

On one hand, the urgency of global climate governance is increasingly apparent. The Paris Agreement established global temperature control targets, propelling nations worldwide toward net-zero emissions in what has become an irreversible global trend. Against this backdrop, China's "dual carbon" goals represent both a profound domestic systemic change and a significant contribution to global climate governance[2].

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On the other hand, the wave of digitalization is reshaping the global economic landscape with unprecedented breadth and depth. With data as its key factor of production and digital technology as its core driver, the digital economy has emerged as a new engine for global economic recovery and growth[3].

However, these two transitions are not inherently synergistic. Digitalization, as a powerful accelerator, has an indeterminate impact in the absence of prudent governance. Without effective guidance, it may merely optimize an existing, fossil-fuel-based, carbon-intensive steady state, ultimately creating a more efficient but equally unsustainable future. While digital technologies can empower various sectors to conserve energy and reduce emissions, their own substantial energy consumption and the systemic "rebound effects" they induce also pose severe carbon emission risks[4]. This inherent tension means the success or failure of the "twin transition" depends on our ability to consciously and systematically guide the digitalization process to serve, rather than deviate from, global decarbonization objectives.

This challenge is particularly acute in the realm of international trade. As the global extension of the digital economy, digital trade is profoundly altering the form and structure of traditional international commerce. Concurrently, carbon-based trade policies, exemplified by the European Union's Carbon Border Adjustment Mechanism (CBAM), are directly transmitting the pressures of climate governance to global supply chains, reshaping the rules of international competition[5]. This renders previous research frameworks that simply categorized digital trade as an "opportunity" or "challenge" inadequate. Likewise, analytical perspectives that treat these two major trends as parallel forces can no longer capture their complex synergistic and conflicting relationships. The essence of the problem is governance, not technology; its outcome is not predetermined but depends on the rules and structures we create to guide technology toward sustainable goals.

Therefore, the central question of this study is not to judge the pros and cons of digital trade for decarbonization but to pose a more forward-looking governance question: *How should we proactively and systematically govern international trade, as a complex socio-technical system, to ensure that digitalization genuinely accelerates, rather than hinders, the global economy's transition to net-zero emissions?*

To answer this question, this paper aims to transcend the static "enabling-rebound" dyadic framework of traditional research by introducing and applying Socio-Technical Transition (STT) theory and its core analytical tool, the Multi-Level Perspective (MLP). This provides a novel, dynamic, and systemic analytical framework for understanding and governing green digital trade. This paper posits that STT theory can integrate the macro-pressures of climate governance (landscape), the structural inertia of the existing international trade system (regime), and the micro-level green digital innovations of firms (niches) into a unified analytical framework, thereby revealing the internal dynamics, resistances, and possible pathways of the transition.

The paper is structured as follows: Section 2 critically reviews the contributions and limitations of the "enabling-rebound" framework and elaborates on the MLP framework as the core theoretical innovation. Section 3 applies the MLP "landscape" perspective to analyze how the EU's CBAM, as a powerful exogenous pressure, destabilizes and reshapes the incumbent international trade "regime." Section 4 focuses on the "niche" level, proposing and elaborating on "Digital Carbon Competitiveness" as an emerging core corporate capability and analyzing its potential as a breakthrough for transition. Section 5, based on the preceding analysis, constructs an integrated "multi-level governance framework" for micro, meso, and macro interventions and proposes systematic policy recommendations. Finally, Section 6 summarizes the entire paper and points to future research directions.

The main contributions of this paper can be summarized in three points:

C1: Extending MLP theory to the domain of international trade by theoretically analyzing how the datafication of carbon reconfigures regime rules under new global carbon constraints.

C2: Conceptualizing "Digital Carbon Competitiveness" (DCC) as a dynamic capability and clarifying its transmission mechanism from the micro to the meso level.

C3: Proposing a multi-level governance design and deriving a series of testable propositions connecting CBAM risk exposure, DCC, and firm/trade outcomes.

2 Theoretical Framework: From Dyadic Effects to a Multi-Level Perspective

Existing research has widely applied the "enabling-rebound" dyad to analyze the relationship between information and communication technology (ICT) and energy systems, but few studies have applied it to international trade as a socio-technical system. Similarly, although MLP has been widely used to analyze energy and transport transitions, its application in the governance of trade under global carbon constraints remains to be explored[6]. To systematically analyze the complexity of green digital trade, this study first reviews and deepens the foundational theory on the environmental impact of digitalization—the "enabling-rebound" dyadic framework. Subsequently, to overcome its static nature and technological determinism, this paper introduces the Multi-Level Perspective (MLP) from socio-technical transition theory to construct an analytical framework better suited for capturing the process of systemic, dynamic change.

2.1 The Foundational Tension: The "Enabling-Rebound" Dyad in the Digital Age

The net environmental impact of digitalization, particularly its effect on energy consumption and carbon emissions, has long been a focal point of academic debate. The core of this debate stems from the inherent duality of digital technology, which can be summarized as the theoretical tension between the "enabling effect" and the "rebound effect"[7]. This framework serves as the fundamental starting point for understanding the relationship between digitalization and decarbonization.

The Enabling Effect refers to the positive impact of digital technology in reducing the carbon intensity of the entire society by empowering various economic and social sectors to conserve energy and reduce emissions through its functions of penetration, substitution, and optimization. Its mechanisms have been extensively studied and are mainly reflected in optimizing industrial structures, enhancing energy efficiency, promoting green innovation, and improving environmental governance[8].

The Rebound Effect, associated with the Jevons Paradox, reveals the non-linear and complex relationship between technological progress and energy consumption. The theoretical roots of this effect can be traced back to the 19th-century British economist William Stanley Jevons, who observed that while technological advancements improved the efficiency of coal use, the resulting cost reduction stimulated broader application, ultimately leading to an increase in total coal consumption[9]. This phenomenon, now known as the "Jevons Paradox," represents the most extreme form of the rebound effect[10]. In the context of the digital economy, the mechanisms of the rebound effect are particularly complex and can be divided into direct, indirect, and macroeconomic effects, such as the immense energy consumption of digital infrastructure itself[11].

The debate within the "enabling-rebound" framework suggests that the impact of the digital economy on carbon emissions may not be linear. Some studies have introduced the Environmental Kuznets Curve (EKC) hypothesis to describe this dynamic relationship. The EKC hypothesis posits that in the early stages of economic development, environmental pollution intensifies with rising per capita income, but after reaching a certain level (the "turning point"), the degree of environmental pollution decreases with further increases in per capita income, exhibiting an inverted U-shaped relationship[12]. Applied to the digital economy, some research suggests a similar inverted U-shaped relationship may exist between the development of the digital economy and carbon emissions[13].

In summary, the "enabling-rebound" dyad provides a basic analytical tool for understanding the environmental impact of digitalization, while the EKC hypothesis further reveals the dynamic and non-linear characteristics of this impact. However, these frameworks tend toward technological determinism; they excel at describing the “outcomes” of technology application but struggle to explain the more complex socio-economic processes that produce these outcomes. Addressing these deeper governance issues requires a theoretical framework capable of analyzing systemic change.

2.2 A Systemic Lens: The Multi-Level Perspective on Sustainability Transitions

Socio-Technical Transition (STT) theory provides a powerful theoretical toolbox for analyzing large-scale, long-term, and fundamental changes in social systems[14]. The theory posits that the fulfillment of societal functions—such as energy, transportation, agriculture, and trade—relies on “socio-technical systems,” which are tightly coupled configurations of technology, regulations, markets, user practices, cultural meanings, and infrastructure. These systems exhibit strong path dependency and lock-in effects, making them highly resistant to fundamental change[15].

The core analytical tool of STT theory is the Multi-Level Perspective (MLP), which explains the transition process as the result of dynamic interactions among three distinct analytical levels[16]:

Socio-technical Landscape (Macro-level): This is the outermost macro-context, composed of slow-changing external factors that individual actors can hardly influence in the short term. Examples include global climate change, macroeconomic trends, geopolitical landscapes, deep-seated cultural values, and major strategies like China’s “dual carbon” goals. Changes at the landscape level exert pressure on the lower-level systems, creating ”windows of opportunity” for transition.

Socio-technical Regime (Meso-level): This is the core of the system, representing the dominant structures, rules, and practices in society. It is a stable configuration composed of mainstream technological standards, industrial chains, market structures, laws and regulations, policy paradigms, and associated actor networks. The regime maintains system stability through powerful lock-in effects, resisting fundamental change. In the context of this study, the incumbent international trade regime is characterized by a logistics system driven by fossil fuels, global supply chains optimized primarily for cost and efficiency, the existing rules of the World Trade Organization (WTO), and the business models of traditional traders.

Niches (Micro-level): These are the incubation spaces for “radical innovations.” Niches are protected networks composed of a few actors (such as start-ups, research institutions) where new technologies, business models, or social practices that differ from the mainstream regime can be experimented with and developed. In this paper, various innovative practices in green digital trade, such as blockchain-based carbon footprint traceability systems and enterprises dedicated to enhancing “Digital Carbon Competitiveness,” constitute the innovative activities at the niche level.

According to MLP theory, socio-technical transitions typically occur through the interaction of these three levels: first, pressure from the landscape level destabilizes the existing regime; simultaneously, innovations at the niche level mature; when landscape pressure opens a ”window of opportunity,” these once-marginal innovations can break through the barriers of the regime, ultimately triggering a reconfiguration of the entire socio-technical regime[17].

By adopting the MLP framework, this study shifts the analytical focus from calculating the static “net effect” of digital technology to understanding a dynamic process of systemic change. This paper contributes to the STT literature by extending the MLP framework to the field of international trade, an area that has received limited attention as a socio-technical system in transition studies. Furthermore, by conceptualizing “Digital Carbon Competitiveness” as a micro-level dynamic capability, this study provides a missing link between firm-level digital transformation and regime-level trade decarbonization, thereby enriching the theoretical understanding of how niche innovations can scale up under global carbon constraints.

3 Landscape Pressure and Regime Destabilization: The EU's CBAM as a Catalyst

Against the grand backdrop of global climate governance, a series of profound "landscape" changes are exerting unprecedented pressure on the incumbent international trade "regime." Among these, the European Union's Carbon Border Adjustment Mechanism (CBAM), which entered its transitional phase in 2023, is arguably the most impactful and transformative catalyst. This section employs the Multi-Level Perspective (MLP) to analyze how CBAM, as a key landscape pressure, is destabilizing the foundations of the traditional international trade regime and creating a "window of opportunity" for green digital innovations at the niche level.

3.1 The Mechanism and Transformative Implications of CBAM

CBAM, often referred to as a "carbon tariff," primarily aims to address "carbon leakage" by ensuring that the EU's climate policies are not undermined by the import of carbon-intensive goods[18]. Its core operational mechanism is built on a set of precise, data-based rules, including the calculation and reporting of embedded emissions, the purchase of certificates linked to the EU's internal carbon price, and cost deductions for carbon prices already paid in the country of export. CBAM initially covers sectors such as iron and steel, aluminum, cement, fertilizers, electricity, and hydrogen[19].

Table 1: Key Features of the EU Carbon Border Adjustment Mechanism (CBAM)

Feature	Description
Legal Basis	The parent regulation establishing CBAM is Regulation (EU) 2023/956 of the European Parliament and of the Council[20]; transitional period reporting rules are defined by Commission Implementing Regulation (EU) 2023/1773[21].
Timeline	"Transitional reporting phase from Q4 2023 to end of 2025 (quarterly reports, default or actual values may be used); financial obligations begin in 2026; free allowances under the EU Emissions Trading System (EU ETS) are phased out between 2026 and 2034."
Initial Scope	"Iron and steel, aluminum, cement, fertilizers, electricity, hydrogen (with potential future expansion to downstream products)."
Pricing Mechanism	"CBAM certificate prices are linked to the weekly average auction price of EU ETS allowances, with deductions for verified carbon prices already paid in the country of origin."
Data Priority	"A progressive shift from using default values to requiring certified, installation-level actual emissions data, aligned with the EU's Monitoring, Reporting, and Verification (MRV) system."

From an MLP perspective, the revolutionary nature of CBAM lies not in its function as a trade tool, but in its fundamental alteration of the "rules of the game" of the international trade regime. By mandatorily converting the carbon content of products into a quantifiable, verifiable, and priceable direct trade cost, CBAM profoundly reshapes the underlying logic of international competition. It heralds the dawn of a new era where competition based on carbon efficiency is becoming the new normal in global trade. For clarity, the key features of CBAM are summarized in Table 1.

3.2 From “Green Barrier” to ”Regime Destabilization”

While often perceived as a ”green barrier,” from a systemic transition perspective, CBAM’s true power lies in its role as a potent exogenous pressure that objectively serves to “destabilize the regime” and “force transformation.” For major exporting countries like China, the implementation of CBAM constitutes a direct and significant shock. In 2023, China was the EU’s largest partner for imports of goods, with trade flows containing a substantial volume of CBAM-covered products[22]. According to industry estimates cited by the Center for Strategic and International Studies (CSIS), from 2026, CBAM could increase the cost of Chinese steel exports to Europe by 4% to 6%, and this impact will continue to grow as free allowances are phased out[23].

This precise, euro-denominated cost pressure compels businesses and governments to re-evaluate their production methods, energy structures, and carbon management capabilities. This pressure is predictable and escalating. The gradual phase-out of EU ETS free allowances between 2026 and 2034 creates a long-term, intensifying landscape pressure, distinct from a one-off, sudden shock[24]. It systematically erodes the economic viability of the carbon-intensive status quo, forcing actors to adopt long-term strategic responses rather than short-term tactical evasions, thereby profoundly shaking the old carbon-locked development path.

3.3 The Digital Response: Cracking Carbon Constraints with Data-Driven Logic

The transformative power of CBAM is fundamentally rooted in its reliance on data. The entire mechanism’s operation is built upon a reliable, transparent, and traceable flow of data[25]. In particular, its reporting requirement shifts from default values to “verified installation-level actual emissions data,” which fundamentally alters the basis of competition[21]. Enterprises must now prove their carbon efficiency with credible data, not just produce goods. This creates a clear entry point for digital response strategies and opens up vast space for niche-level digital innovations.

The essence of CBAM is the conversion of a vague environmental externality into a precise, data-driven supply chain management problem. The most effective tools for addressing this problem are digital technologies.

Establishing Credible Carbon Footprint Accounting and Traceability Systems: Enterprises can leverage the Industrial Internet of Things (IIoT) and blockchain technology to build full-chain carbon footprint tracking platforms, providing immutable and credible proof of a product’s low-carbon attributes[26].

Implementing Fine-grained Digital Carbon Management: By deploying Energy Management Systems (EMS) and Manufacturing Execution Systems (MES), combined with big data analytics, companies can accurately identify carbon emission hotspots and continuously optimize carbon performance.

Promoting Supply Chain Collaborative Decarbonization: Leading enterprises can build digital supply chain collaboration platforms, making carbon performance a core indicator in their supplier evaluation systems, thereby driving the green transformation of the entire supply chain.

In conclusion, the powerful pressure from the “landscape level,” represented by CBAM, is profoundly changing the operational logic of the international trade “regime.” It objectively acts as a potent catalyst, accelerating the deep integration of digitalization and carbon management.

4 Niche Development and the Rise of “Digital Carbon Competitiveness”

In the MLP framework, the realization of a transition ultimately depends on mature niche innovations seizing a ”window of opportunity” to achieve a breakthrough. In the face of data-driven carbon constraints like CBAM, a new type of niche innovation is emerging, which this study conceptualizes as ”Digital Carbon Competitiveness”.

4.1 The Micro-Foundations: Empirical Links between Corporate Digitalization and Carbon Performance

The construction of "Digital Carbon Competitiveness" is built upon micro-level evidence of the positive impact of corporate digital transformation on environmental performance. A growing body of empirical research is beginning to reveal this intrinsic link. Studies using panel data from Chinese listed companies consistently find that digital transformation significantly reduces corporate carbon intensity[27]. This effect is realized through key pathways such as promoting green technology innovation and improving energy efficiency[28]. Although some studies have noted the possibility of a U-shaped relationship, where the initial investment in digital infrastructure may temporarily increase emissions (a form of rebound effect), the long-term net effect is a reduction in carbon intensity as enabling effects like process optimization and green innovation become manifest[29]. While some research suggests the possibility of a U-shaped relationship, this paper does not take a pre-emptive stance on the specific functional form; the identification of this relationship is ultimately an empirical question, dependent on the interplay between initial investment costs and long-term efficiency gains.

4.2 Conceptualizing and Operationalizing Digital Carbon Competitiveness (DCC)

Based on this micro-level evidence, this study defines "Digital Carbon Competitiveness" as: *a dynamic capability for an enterprise to integrate digital technologies to achieve precise carbon measurement, fine-grained management, credible reporting, and strategic abatement, thereby gaining a sustainable competitive advantage under global carbon constraints.* This capability transcends traditional cost or quality advantages and is composed of three core dimensions:

Table 2: Operationalizing Digital Carbon Competitiveness (DCC) as a Dynamic Capability

Dimension	**Core Capability**	**Key Performance Indicators (KPIs)**	**Link to EU Regulatory Framework**
A. Measurability & Traceability	To sense and measure carbon emissions with high granularity and integrity across the value chain.	"- Scope 1, 2, & 3 emissions coverage (%). - Share of products with verified Product Carbon Footprints (PCFs). - Supplier carbon data response rate & quality score. - Real-time energy consumption monitoring (kWh/unit)."	ESRS E1: Mandates disclosure of Scope 1, 2, and 3 GHG emissions, and total energy consumption[31]. EU Data Act: Provides legal right for users to access data from connected products (e.g., machinery), enabling accurate measurement[32].
B. Analytics & Optimization	"To seize opportunities by analyzing carbon data to optimize processes, reduce emissions, and lower costs."	"- Energy/carbon intensity reduction rate (%). - PUE (Power Usage Effectiveness) for data centers. - Number of AI-driven process optimization projects. - Verified CO2e savings from operational changes (tons)."	ESRS E1: Requires disclosure of transition plans and mitigation actions[31]. This dimension represents the "how" of those plans. EU Data Act: Facilitates data flow to analytics platforms, unlocking value from industrial data[32].
C. Trust & Valorization	To reconfigure and translate verified low-carbon attributes into tangible market and financial advantages.	"- Third-party verification/assurance rate for carbon data. - Share of transactions recorded on an immutable ledger. - Green financing premium/discount (basis points). - Price premium or market share gain for low-carbon products."	ESRS: Requires limited assurance (auditing) of sustainability reports, driving the need for trustworthy data[33]. CBAM: Verified low-carbon data directly translates into lower border tariffs, valorizing trust.

Carbon Data "Measurability" and "Traceability": The ability to use technologies like IoT and digital twins to collect real-time, accurate carbon emissions data throughout the entire product lifecycle and supply chain.

Carbon Management "Granularity" and "Optimization": The ability to use tools like big data analytics and artificial intelligence to mine the value of carbon data, identify emission hotspots, and achieve continuous, fine-grained improvement in carbon performance.

Carbon Information "Credibility" and "Valorization": The ability to use technologies like blockchain to provide immutable, credible proof for carbon footprint data, effectively respond to external verification, and translate certified low-carbon attributes into market advantages.

Defining "Digital Carbon Competitiveness" as a "dynamic capability" is a significant theoretical step[30]. It suggests that in the era of the twin transition, competitive advantage stems not from simply possessing a green technology (a static asset), but from the routines and processes embedded within the organization to learn, adapt, and reconfigure its operations in a constantly changing environment. To transform this concept from an abstract theory into a measurable construct, thereby providing a path for future empirical research, the operationalization framework is proposed (Table 2).

This operationalization framework is more than a list of indicators; it depicts the "socio-technical system" within a firm. Dimension A (Measurability) is the firm's direct response to CBAM's data mandate. Dimension B (Optimization) is how the firm uses this data to improve processes and reduce carbon costs. Dimension C (Valorization) is the pathway through which the firm translates internal improvements into external market advantages (e.g., lower financing costs, product premiums). Therefore, DCC is the crucial transmission mechanism that converts external, macro landscape pressure (CBAM) into tangible, micro-level corporate capabilities and competitive outcomes. Without this dynamic capability, landscape pressure may simply be a punitive cost rather than a catalyst for change.

4.3 "Digital Carbon Competitiveness" as a Niche Innovation

Within the MLP framework, "Digital Carbon Competitiveness" is precisely the kind of radical innovation nurtured and developed by forward-thinking "niche actors" (pioneer firms). These firms proactively invest in building digital and carbon management capabilities, experimenting with new business models that transform sustainability from a cost center into a value creation center[34]. These niche innovation practices, such as intelligent logistics platforms, blockchain-based carbon traceability, and AI-driven green finance, collectively constitute the "niche" ecosystem for the green digital trade transition. When landscape pressure is sufficiently strong, these successfully validated technologies and business models have the potential for large-scale adoption, ultimately propelling the entire international trade system toward a new, green, and digital paradigm.

5 Governing the Twin Transition: A Multi-Level Framework

To successfully navigate the "dual effects" of digital trade and proactively lead the international trade system toward a green, digital future, a systemic governance framework that aligns with MLP theory is necessary. This framework emphasizes synergistic policy interventions at the niche, regime, and landscape levels.

5.1 Testable Propositions for Future Research

Based on the theoretical framework presented, a series of propositions can be derived for future empirical investigation. These propositions link the core concepts of this paper (CBAM, DCC) in a causal manner:

P1 (Landscape → Regime): Higher firm-level exposure to CBAM (effective carbon price at the product/sector level) will be positively associated with an increase in the scope and quality of corporate carbon disclosures and investments in process upgrades.

P2 (Niche Performance): Controlling for other factors, firms with higher pre-existing levels of DCC will exhibit lower carbon intensity and maintain or increase their EU market share post-CBAM implementation compared to firms with lower DCC.

P3 (Interaction Effect): The negative impact of CBAM on export profitability will be significantly smaller for firms with high DCC. Furthermore, the interaction of CBAM pressure and high DCC will accelerate the adoption of verifiable renewable energy sources to reduce Scope 2 emissions.

These propositions can be tested empirically using firm-level panel data with a Difference-in-Differences (DiD) research design, where the implementation of CBAM serves as the policy shock.

5.2 Niche Incubation (Micro-Level Intervention)

The governance objective at this level is to accelerate the emergence, maturation, and diffusion of green digital technologies and "Digital Carbon Competitiveness." The primary role of government is to create a "protected space" for these innovations to grow[35]. Policy instruments include targeted support for R&D in key technologies (such as blockchain-based MRV systems), the construction of public digital service platforms to lower the technological barrier for small and medium-sized enterprises (SMEs), and the implementation of green-oriented public procurement to create early markets for innovative firms.

5.3 Regime Reformation (Meso-Level Intervention)

The objective here is to break the lock-in effects of the carbon-intensive trade regime and create favorable "market formation" conditions for niche innovations. The incumbent system must be "unlocked" to accommodate new ideas. Policy instruments include deepening and expanding carbon pricing mechanisms to create stable price signals, developing green digital finance linked to credible carbon data, and building green digital infrastructure with strict energy efficiency standards, such as setting minimum renewable energy shares or Power Usage Effectiveness (PUE) thresholds, to manage the "rebound effect" of digitalization itself.

5.4 Landscape Shaping and Steering (Macro-Level Intervention)

The goal at the macro level is to actively participate in and influence the evolution of global trends, transitioning from a passive recipient of rules to a proactive shaper. Policy instruments include conducting active "carbon diplomacy" to ensure domestic MRV systems gain international mutual recognition, leading the development of international standards for green digital technologies, and building international alliances such as a "Green Digital Silk Road" to promote common standards and governance experiences.

5.5 International Perspectives on Green Digital Trade Governance

Comparing the above framework with the practices of other major economies lends it greater real-world relevance. Each economy is navigating the twin transition according to its unique institutional and economic context.

The European Union: Building a Coherent Regulatory Ecosystem. The EU has positioned itself as a global regulatory leader, proactively shaping the rules for green and digital trade. Its strategy is characterized by comprehensive legislation designed to align its trade policy with its ambitious "European Green Deal" [36]. This integration is further exemplified by the interplay between the European Sustainability Reporting Standards (ESRS), which mandate detailed climate disclosures, and the EU Data Act, which sets rules for sharing industrial data, creating a coherent regulatory ecosystem where trade, sustainability, and data governance are mutually reinforcing[37]. The EU's approach leverages its market power to export its standards, creating a level playing field that effectively sets the terms for global green digital trade[38]. The EU's model functions as a self-reinforcing system. The EU Data Act (Regulation (EU) 2023/2854) establishes the legal right for users, including businesses in a value chain, to access and share data generated by connected products and services, thereby unlocking vast reservoirs of industrial data[32]. The ESRS, particularly ESRS E1 on Climate Change, creates the demand for this data by mandating that companies report granular, audited information on their Scope 1, 2, and 3 GHG emissions and energy consumption[31]. To comply with mandatory Scope 3 reporting, a company needs data from its suppliers; the Data Act provides the legal tool to acquire that data. Finally, CBAM monetizes this data at the border. Accurate, verified data—enabled by the Data Act and mandated by ESRS—leads directly to lower carbon tariffs. This powerful feedback loop makes DCC a competitive necessity.

The United States: A Market-Driven, Fragmented Approach. The U.S. approach is more market-driven and has recently shown vacillation in internal policy debates. While agencies like U.S. Customs and Border Protection have developed a "Green Trade Strategy" to incentivize green practices[39], the U.S. has shown ambivalence in international digital trade negotiations, notably scaling back its support for certain e-commerce rules in the 2023 WTO negotiations. This move has sparked serious bipartisan concern in Congress about the U.S. ceding its leadership role in setting global digital trade rules[40]. This reflects a complex interplay between promoting digital commerce, national security concerns, and a less centralized regulatory philosophy compared to the EU[41].

Japan: A Strategic Push for "Data Free Flow with Trust" (DFFT). Japan is pursuing a "Green Transformation (GX)" strategy, which positions digital innovation as a central pillar for achieving carbon neutrality by 2050[42]. In international forums, Japan has been a leader in digital trade rule-making, championing concepts like "Data Free Flow with Trust (DFFT)." This principle originated from its national-level "Society 5.0" vision for digital transformation and was subsequently promoted in international venues like the G7[43].

These divergent paths highlight a global trend toward integrating climate and digital policies but also reveal different philosophies regarding regulation, market intervention, and international cooperation. This geopolitical divergence suggests that the rules for global green digital trade are not converging but are becoming an arena for geopolitical competition. This provides a rich context for this paper's call to proactively "shape the landscape."

6 Conclusion and Future Outlook

6.1 Research Contributions and Policy Implications

This study aims to provide a more original and systematic analytical perspective for understanding and governing the complex phenomenon of green digital trade. Its theoretical contribution is twofold. First, by introducing Socio-Technical Transition (STT) theory and its Multi-Level Perspective (MLP) as a new analytical framework, it moves beyond the static "enabling-rebound" dyad. This shifts the research focus from a simple assessment of technological impacts to a dynamic analysis of systemic change, extending the MLP framework to the under-researched domain of the international trade system. Second, it conceptualizes and operationalizes "Digital Carbon Competitiveness" as a firm-level dynamic capability, providing a crucial micro-meso link to explain how niche-level innovations can drive the decarbonization of the broader trade regime under global carbon constraints.

From a policy perspective, the main implication of this paper is the need for a holistic, multi-level governance approach. By reinterpreting the EU's CBAM not merely as a trade barrier but as a powerful landscape pressure, this study underscores the urgency of adopting proactive rather than reactive response strategies. The proposed framework advocates for synergistic interventions at the niche, regime, and landscape levels, offering policymakers a systematic roadmap. By "nurturing innovation" at the micro level, "reforming the regime" at the meso level, and "steering the landscape" at the macro level, nations can better align their digital trade development trajectories with long-term climate goals, ensuring that the twin transition delivers unified economic, social, and environmental benefits.

6.2 Limitations and Avenues for Future Research

This study is primarily focused on theoretical deduction and framework construction, laying the groundwork for future empirical research. However, it has certain limitations. The proposed analytical framework is relatively complex, and its validity requires testing with more empirical evidence, particularly through cross-national data verification to account for different institutional contexts. Future research can deepen and validate the framework proposed in this study from the following directions:

Quantitative Modeling of Transition Pathways: Employing system dynamics or agent-based models to simulate the interactions between the niche, regime, and landscape levels to provide quantitative support for policy choices.

Quantitative Measurement and Empirical Testing of "Digital Carbon Competitiveness": Based on the indicators in Table 2, construct a scientific "Digital Carbon Competitiveness" evaluation index. Using large-scale firm-level panel data, empirically test the propositions proposed in this paper using methods like Difference-in-Differences (DiD) or event studies to assess the impact of CBAM implementation on firms' carbon performance, financial performance, and export competitiveness.

Comparative Case Studies and Industry Heterogeneity Research: Conduct in-depth comparative case studies of different industries and countries to explore how the transition pathways of green digital trade differ under various technological, market, and policy environments.

Political Economy Analysis of the Transition: Future research should pay closer attention to the political-economic factors in the green digital trade transition, including how vested interests within the incumbent regime resist change and the strategic interactions among different countries in the global rule-setting process.

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