
An Institutional-Technological Framework for Carbon Footprint Tracking in ASEAN Cross-Border Supply Chains

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Abstract: Carbon footprint tracking has become a critical capability for firms in global supply chains, yet adoption remains deeply uneven across ASEAN, and this paper sets out to explain that variation by integrating the Technology–Organization–Environment (TOE) framework with institutional theory into a single Institutional-Technological Framework. The framework is developed through a conceptual, non-empirical theory-building approach, grounded in a narrative review of the sustainability-technology adoption, institutional theory, and ASEAN supply chain governance literatures, and complemented by policy and infrastructure data from the ASEAN Secretariat, the Asian Development Bank, and the International Telecommunication Union. The analysis finds that regulative, normative, and cognitive pressures function as upstream institutional forces, while organizational readiness and technological compatibility operate as conditional enablers that determine whether pressure translates into genuine adoption or symbolic compliance; infrastructure readiness, firm size, and supply chain complexity further moderate these relationships and explain divergent adoption trajectories across member states. Eight falsifiable propositions are derived, specifying the conditions under which institutional pressure fails to produce adoption in resource-constrained, emerging-economy contexts. The framework advances TOE theory by embedding legitimacy-seeking mechanisms within its environmental dimension and contributes to institutional theory by specifying when pressures produce behavioral change rather than symbolic response. Practically, the framework informs policy sequencing, supplier capability investment, and the design of buyer-driven carbon disclosure programs across ASEAN's heterogeneous institutional landscape, offering researchers and policymakers a falsifiable basis for future empirical testing.

Keywords: ASEAN, Carbon footprint tracking, Emerging economies, Institutional theory, Supply chain sustainability, Technology–Organization–Environment framework, Symbolic compliance, Cross-border supply chains.

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INTRODUCTION

Pressure on the international supply chain to account for its carbon emissions continues to intensify as changes in the climate become a greater priority for national governments and companies operating across borders. The Paris Agreement and other rule-based international arrangements have greatly increased the urgency for



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verifiable carbon accounting within international supply networks (IPCC, 2022). Technologies tracking carbon footprints, including IoT-enabled sensors, blockchain information systems, and cloud analytics, provide the capabilities necessary to measure, document, and audit corporate emissions (Kouhizadeh, Saberi, & Sarkis, 2021; Upadhyay, Mukhuty, Kumar, & Kazancoglu, 2021). These new advances help corporations meet the requirements of international standards such as the Greenhouse Gas Protocol and ISO 14064 (Wiedmann & Minx, 2008).

Regulatory changes further strengthen the strategic salience of carbon transparency. The EU's Carbon Border Adjustment Mechanism (CBAM) began its reporting-only phase in 2023 and transitions to full financial obligations, including certificate purchase requirements, in 2026; export-oriented firms in emissions-intensive sectors must provide verified emissions data in order to gain or retain market entry (European Parliament & Council of the European Union, 2023). Signaling the regulatory shift from optional usage to coercive, CBAM adds a novel, trade-cost dimension to the carbon investment decision through adjustments in the relative profitability of firms that do not document auditable emissions records. This variable cost exposure increasingly functions as a supply chain qualification criterion for multinational buyers in ASEAN's automotive, electronics, and FMCG markets, who now routinely request supplier carbon performance data as part of broader supplier scorecards (Busse, Schleper, Niu, & Wagner, 2016; Golini, Longoni, & Cagliano, 2014). Recent evidence further demonstrates that ASEAN electronics and apparel exporters face direct or indirect competitive threats from this CBAM-related cost adjustment, with smaller firms accounting for the bulk of the exposure (Perdana & Vielle, 2022).

The ASEAN region is a particularly important and theoretically interesting setting in which to consider the adoption of carbon tracking. ASEAN's share of global merchandise exports has risen steadily in recent years, reflecting the region's growing weight in global manufacturing networks (ASEAN Secretariat, 2021). Heterogeneity across core dimensions—regulatory structures, digital infrastructure, cultural attitudes toward environmental responsibility, and firms' organizational and digital capabilities—runs unusually deep within and across ASEAN member states (ASEAN Secretariat, 2021). Singapore has one of the region's most advanced systems for carbon management; Malaysia has made substantial progress toward more inclusive sustainability data reporting and climate disclosure requirements; and Cambodia, Laos, and Myanmar have neither the regulatory structure nor the binding elements of digital infrastructure (Asian Development Bank, 2024) to incentivize digital carbon management interventions.

Previous research on the adoption of sustainability technologies has made significant headway in the task of identifying drivers of adoption; however, three limitations of the literature constrain its applicability to the ASEAN context. First, adoption research has drawn mainly on single-country settings—a pattern documented in major reviews and syntheses of sustainability-technology adoption, which note that institutional heterogeneity across jurisdictions remains underexamined (Belabbas & Su, 2026; Dubey et al., 2019; Korhonen, Koskivaara, Makkonen, Yakusheva, & Malkamäki, 2021; Sarkis, Gonzalez-Torre, & Adenso-Diaz, 2010). Second, the use of the TOE framework and institutional theory has been compartmentalized; while both are used separately in the literature, research that attempts to integrate the two approaches is limited, and none of these integration efforts incorporate moderating effects of supply chain complexity and infrastructural factors (Sarkis et al., 2010). Third, most existing conceptual models of adoption confound institutional pressure and organizational capability as purely additive factors, and thus cannot explain the empirical phenomenon of firms experiencing high institutional pressure yet failing to adopt when the requisite capabilities are lacking (Luthra, Kumar, Sharma, Garza-Reyes, & Kumar, 2022; Oliveira & Martins, 2011).

At the heart of all three of these gaps is the concept of symbolic compliance—the tendency of capacity-constrained organizations to signal adoption intent through voluntary disclosures, partial implementations, or third-party certifications that satisfy surface-level legitimacy demands without achieving genuine carbon tracking capability (Delmas & Toffel, 2008). This is the central theoretical problem that this paper seeks to address.

Thus, this paper is organized around two broad research questions: RQ1: How does the institutional environment, including regulative, normative, and cognitive pressures affect the adoption of carbon footprint measurement in ASEAN cross-border supply chains? RQ2: What organizational, technological, and contextual

conditions determine the realization of institutional pressures into adoption rather than isomorphism? This paper attempts to answer these questions by proposing the proposition-based Institutional-Technological Framework rooted in both theoretical integration and contextualization within ASEAN's institutional conditions. The framework contributes to previous knowledge in three ways: reconceptualizing organizational readiness and technological compatibility previously treated as mediating variables, as conditional enablers; specifying the suppression conditions under which institutional pressure fails to produce adoption; and identifying infrastructure readiness and supply chain complexity as moderators that shape ASEAN's divergent adoption pathways. This paper proceeds as follows: literature review on the theoretical building blocks; methodology section on the theory building approach; conceptual framework section on the development of the model and the eight propositions; and discussion on the development of the theoretical as well as practice implications.

LITERATURE REVIEW

Carbon Footprint Tracking in Supply Chains

Carbon footprint tracking pertains to capturing, reporting, and reconciling greenhouse gas (GHG) emissions using comprehensive data across multiple tiers in the supply chain (ideally, Scope 1, 2, and 3 GHG emissions according to the GHG Protocol; Wiedmann & Minx, 2008). Progress in IoT sensing technology, distributed ledger systems based on blockchain, and cloud-based analytical platforms has substantially lessened the technical cost of capturing multi-tier emissions data, even though implementation costs remain prohibitive for resource-constrained firms (Kouhizadeh et al., 2021; Upadhyay et al., 2021). Concurrently, rising costs of compliance with the expanding scope of mandatory Scope 3 disclosures—including under the EU Corporate Sustainability Reporting Directive—have driven stronger demand for supply chain-level carbon metrics (Christmann & Taylor, 2006; Hettler & Graf-Vlachy, 2024). A parallel U.S. Securities and Exchange Commission climate disclosure rule, adopted in 2024, was stayed pending litigation and never took effect; the SEC proposed to rescind it in full in 2026.

The business case for this evidencing activity is not restricted to pure regulation. Firms with verified emissions data have experienced benefits in supply chain visibility, procurement risk reduction, and access to sustainability-linked investment facilities (Busse et al., 2016). In high-value manufacturing supply chains, carbon visibility has become part of supplier qualification standards, such that firms that cannot credibly evidence their emissions metrics are precluded from preferred supplier lists regardless of price or quality (Golini et al., 2014). This market dynamic drives adoption pressures well ahead of regulation for export-dependent ASEAN economies.

Together, these incentives are, however, not enough: adoption also remains patchy. Literature on adopters in emerging economies suggests that institutions are a key factor in adoption dynamics: those with strong institutional pressure and organizational capacity are more likely to adopt, while those without one or the other are likely to delay or abandon adoption altogether (Dubey et al., 2019). This interaction effect is missed by frameworks that treat institutional pressure and organizational capacity as independent, additive causal effects. The absence of either causes firms with high buyer pressure but inadequate IT, financial, and human capital and capabilities not to bide their time and scale back their adoption, but instead to jump ship, abandoning the process altogether and seeking alternative (cost-sensitive) means of legitimation like third-party standards and self-reporting mechanisms, which attract lower implementation costs but have weak assurances (Delmas & Toffel, 2008). This is more common than believed for ASEAN SMEs.

The TOE Framework: Strengths and Limitations

The TOE framework (Tornatzky, Fleischer, & Chakrabarti, 1990) is still the most utilized framework for organizational technology adoption, with multiple empirical supports found in enterprise systems, e-commerce, cloud computing and even new applications in the area of sustainability technology adoption (Oliveira & Martins, 2011). Its three constructs involve all aspects of adoption drivers identified: technological (relative advantages, complexity, and compatibility); organizational (size, slack resources, top management

support, and IT capability); and environmental factors (competition, pressure from trading partners, and government regulation).

As applied to technology adoption in the context of environmental sustainability, the TOE framework has demonstrated predictive ability across different country contexts (Sarkis et al., 2010). However, the framework exhibits three systematic limitations in fragmented institutional contexts such as ASEAN: Firstly, the environmental dimensions of the TOE framework view market support (competition, buyer pressure) and regulation (regulatory mandates, social norms) as functionally equivalent when they seem to work through different mechanisms and elicit different organizations' responses (DiMaggio & Powell, 1983). Secondly, the TOE framework fails to set specific conditions to clarify how environmental pressures are delineated into the adoption decision, treating such delineation as automatic when they, indeed, require the involvement of technical capability and compatibility between new technology and existing organizational targets (Tornatzky et al., 1990). Thirdly, the TOE framework was developed and validated primarily in relatively similar national institutional settings; the framework's extension to cross-border supply chains spanning multiple legal regimes has not been theoretically developed.

Institutional Theory: Three Pillars and Their Mechanisms

Institutional theory, as Scott (2014) formulates it in his three-pillar framework, identifies regulative, normative, and cognitive processes through which the institutional environment influences actions. In terms of empirical implications, these processes can be differentiated as follows. The regulative process requires that the organization be coerced using the threat of penalty: the greater risk of constraint compels the organization to act in ways that minimize the likelihood of legal sanctions, maintain operational licenses, or preserve market access through their adoption of practices (DiMaggio & Powell, 1983; Scott, 2014); the normative process requires an obligation: the greater the normative legitimacy of the actors in the field through whom other organizations gain their own legitimacy (e.g., professional buyers, industry associations, certifiers), the greater the incentive for an organization to conform to the organizational practices advocated by those actors in order to garner their approbation (Scott, 2014); and the cognitive process operates through taken-for-granted logics, symbols, and assumptions: the more an organization's procedures align with what a legitimate actor in its field is understood to do, the more likely the organization is to conform (Scott, 2014).

These three mechanisms produce qualitatively different adoption dynamics. Regulative pressure produces compliance that is calibrated to enforcement threat; firms adopt just enough to meet the penalty without internalizing the core practice being implemented (Delmas & Toffel, 2008). Normative pressure produces compliance that is directly coupled to customer or association dictates. Adoption depth will be as specific as the normative imperative. Cognitive pressure produces the most intense compliance: if firms hold an a priori belief that carbon transparency is part of good management, they are likely to deploy a highly sophisticated, multi-level abatement-tracking mechanism rather than a minimally compliant one. These implications are significant, but no categorization of technology choices has been provided in the adoption literature. A central debate in institutional theory about the interplay of institutional pressure and organizational agency has centered on the extent of determinism ascribed to institutional fields; early neo-institutional literature tended to focus on homogeneity-inducing, deterministic effects of institutional fields, which lead organizations to move toward isomorphism when exposed to similar institutional pressures (DiMaggio & Powell, 1983). Later studies have shown wide variation in the response of organizations that have been nominally subjected to similar pressures (Battilana & Dorado, 2010; Greenwood, Raynard, Kodeih, Micelotta, & Lounsbury, 2011) and have argued that such phenomena were caused by differences in organizations' capacity, strategic behavior, and dimensions of embeddedness in different, competing institutional logics. This discussion is relevant to ASEAN, where firms in different member states are being subjected to nominally similar global buyer demands but show remarkably different levels of adoption that cannot be explained by institutional pressure alone.

ASEAN-Specific Context: Institutional Fragmentation and Digital Heterogeneity

ASEAN's institutional setting is not just diversified but also fragmented in ways that create structural barriers to cross-border carbon tracking. Member states maintain different standards for corporate reporting, cooperation regimes, and digital data formats, meaning a multi-jurisdictional supply chain linking Vietnam, Indonesia, and Singapore must simultaneously satisfy three sets of often incompatible institutional requirements (Asian Development Bank, 2024). Compounding this institutional fragmentation is the region's deeply uneven digital connectivity: the International Telecommunication Union (2022) ranks Singapore among the world's top-tier connected economies while Cambodia and Myanmar sit near the bottom. Firms seeking to standardize carbon tracking across such infrastructure heterogeneity face not only cost barriers but hard interoperability constraints that cannot be resolved through organizational goodwill alone.

SME dominance is another feature that sets the ASEAN region apart from the organizational populations under study by most TOE and institutional theory frameworks. Over 60–70 percent of supply chain members in Indonesia and Vietnam are SMEs, which rarely have the capital resources, information technology capacity or sustainability knowledge necessary to operationalize large-scale carbon tracking mechanisms (OECD, 2023). However, buyer-driven normative pressures, which come from all sizes of multinational customers, do not tailor their disclosure requests, creating an adoption gap that market mechanisms would be unable to fill on their own. It is this mismatch in organizational power and legitimacy that underlies ASEAN's adoption gap and motivates the conditional enabler concept introduced in the models below.

Local empirical work confirms these trends. Malaysian and Thai manufacturers most commonly report normative pressure as the impetus for adopting new technology, sufficient at times to compensate for weak or absent domestic regulation (Asian Development Bank, 2024). Vietnamese electronics exporters report adopting 'minimum viable' carbon-emissions-monitoring tools solely to meet buyers' scorecards rather than to improve ex-post emissions visibility or control (World Bank, 2022), consistent with surface compliance under normative rather than cognitive pressure. Indonesian palm oil and apparel supply chains exhibit the most constrained adoption, where infrastructure gaps and SME dominance suppress adoption even in the presence of strong international normative pressure (OECD, 2023).

The Philippines and Thailand present instructive cases that further demonstrate how this framework's conditional logic functions. The Philippines' Securities and Exchange Commission shifted from a voluntary, comply-or-explain sustainability reporting framework to mandatory International Sustainability Standards Board (ISSB)-aligned disclosure requirements for listed companies and large non-listed entities, phased in beginning with fiscal year 2026 (Philippine Securities and Exchange Commission, 2025). While regulatory pressure is increasing, the involvement of supply chains in carbon accounting appears limited by the archipelagic geography of the Philippines, which complicates distribution logistics and leads to a patchwork of digital infrastructure coverage across island provinces, epitomizing how infrastructure readiness can be a barrier to adoption even as formal regulative pressure is increased. Thailand provides a somewhat more sophisticated institutional context. The Thailand Greenhouse Gas Management Organization (TGO) has operated the Carbon Footprint for Organization (CFO) certification program since 2011, and the CFO scheme has been integrated into the Industrial Estate Authority of Thailand's Eco-Industrial Town standard, embedding carbon footprint requirements into normative expectations for industrial zone participation. Survey evidence confirms that buyer pressure from export market customers, particularly in automotive and chemical supply chains linked to Japanese- and European-sourcing networks is among the primary drivers of CFO adoption among Thai manufacturers, though adoption remains uneven and participation rates across SMEs are limited (Sureeyatanapas, Yodprang, & Varabuntoonvit, 2021). These two cases illustrate how identical institutional mechanisms can yield different adoption outcomes depending on whether the underlying enabling conditions are in place. This regional tightening is not universal: a parallel U.S. Securities and Exchange Commission climate disclosure rule, adopted in 2024, was stayed pending litigation and never took effect, and the SEC proposed to rescind it in full in 2026 (U.S. Securities and Exchange Commission, 2026), underscoring that mandatory carbon-disclosure regimes remain contested even among developed-economy regulators.

Toward Integration: Gaps in Existing Frameworks

Three specific gaps identified in the review motivate the framework designed in this paper. The first gap is the lack of any framework that combines institutional theory's three-pillar distinction with TOE's focus on organizational and technological factors as applied to cross-border supply chains. Existing integrations conflate institutional pressure and TOE environmental factors into a single, equivalently powerful variable, effectively collapsing two theoretically different mechanisms into one (Sarkis et al., 2010). The second gap is the general absence of directions of interaction within institutional pressure, TOE organization, and TOE technology. Most existing frameworks do not specify whether institutional pressures are channeled through organizational and technological factors that are actively engaged, or ones that go unaddressed. As such, their direction is correct, but their effect size is too weak to capture the high explanatory power observed in ASEAN adoption decision data. The third gap is the problem of unproposed moderators of the relationship of institutional forces and TOE determinants. Infrastructure heterogeneity and supply chain complexity have emerged as adoption's motivational constraints in descriptive surveys, but their effect sizes as moderators have not been theorized. Thus, the present framework must address all three gaps by developing a comprehensive proposition set that achieves the theoretical balance of TOE and institutional theory.

METHODOLOGY

This study employs a conceptual, non-empirical theory-building approach appropriate for understanding a complex, multi-dimensional phenomenon like cross-border carbon tracking in ASEAN, where the theorist ought to be interested in developing new theoretical explanations and generating falsifiable hypotheses for empirical investigation rather than applying existing hypotheses to primary data. A conceptual theory-building approach is found necessary in this paper because there is thus far no framework that explicitly combines institutional theory's three-pillar distinction with the organizational and technological components of the TOE framework in the case of ASEAN cross-border supply chains; constructing such a framework therefore represents a necessary step toward subsequent empirical work (Okhuysen & Bonardi, 2011; Whetten, 1989). Hence, adhering to Whetten (1989) criteria for theorizing, the paper explicitly specifies which constructs are involved (constructs), how the constructs relate to each other (the relations), how the relations might lead to other factors and assumptions that support the framework (the causal logic), and where and under what context these relations become generally valid (boundaries). The framework combines the established TOE framework (Tornatzky et al., 1990) and institutional theory (DiMaggio & Powell, 1983; Scott, 2014), following Okhuysen and Bonardi (2011) criteria of addressing asymmetrical sides of the same object, generating non-trivially reduced propositions, and enabling falsifying statements. The framework was constructed through a narrative review of landmark and critical works in three areas of intersecting literatures: the adoption of sustainable technology, institutional theory as relevant to organizations, and ASEAN supply chain governance. Instead of a systematic search in an electronic database, the review was conceptually driven: works were chosen according to their impact on the conceptual framework's identified lacunae, their primacy within the literature, and their explanations of the relevant institutional or organizational context for emerging-economy supply chains. This is suitable for conceptual theory-building, where the goal is preserving conceptual coherence and identifying lacunae, rather than achieving exhaustive coverage of empirical complexity (Okhuysen & Bonardi, 2011; Whetten, 1989). The narrative review was complemented by consulting policy documents and institutional reports from the ASEAN Secretariat, the Asian Development Bank (ADB) and the European Commission, as well as indicators of digital readiness and infrastructure from the World Bank and the International Telecommunication Union (ITU). These sources formed the empirical basis for establishing the ASEAN-specific contextualization of the framework and for determining the boundary conditions and moderating variables. In line with research advocating context-sensitive theorizing (e.g., Johns, 2006; Tsui, 2004), the framework does not simply apply existing theories as if ASEAN's institutional characteristics were theory-neutral but explicitly contextualizes the application of these theories into the ASEAN setting. Candidate theoretical mechanisms (e.g., conditional enablement) were compared in a process of abductive theorizing

(Dubois & Gadde, 2002) against ASEAN evidence (e.g., Vietnamese firms' high reliance on minimum-viable adoption tools, and cases of non-adoption among Vietnamese firms driven by infrastructure-related cost constraints, etc.), iteratively redefining the boundary conditions and structure of propositions through multiple theory-to-evidence loops until deriving as plausible an explanation as possible for the observed technology-adoption practices in ASEAN. This process ultimately led to the formulation of theory-based propositions (eight in total), firmly grounded in theory and situated within the ASEAN-specific institutional context. Where apparent, country illustrations focus on Singapore, Vietnam, Indonesia, Malaysia, and Thailand, as those countries populate the most import-export links in the regional manufacturing export network, and/or are highly covered by empirical studies we drew on. The framework should, in principle, extend across all ASEAN countries. Future work should seek to apply it to study adoption patterns in the least researched ASEAN states, such as Cambodia, the Philippines, Brunei, Laos, and Myanmar.

CONCEPTUAL FRAMEWORK

Overview and Framework Logic

This Institutional-Technological Framework advances the institutional perspective in the consideration of channeling the adoption process by arguing that institutional pressures serve as upstream forces that shape the decision space the firm faces by making adoption more or less arduous. Instead of viewing institutional pressure as an absolute trigger for adoption, the framework instead postulates two types of intervening conditions. Organizational readiness and technological compatibility operate as conditional enablers that determine whether institutional pressure translates into adoption or is instead deflected into less costly, symbolic legitimization paths. Infrastructure readiness, firm size, and supply chain complexity act as contextual moderators that modify the strength of the relationship between institutional pressure and the respective conditional enablers, producing the varied adoption trajectories of firms across the ASEAN context. Figure 1 displays the framework.

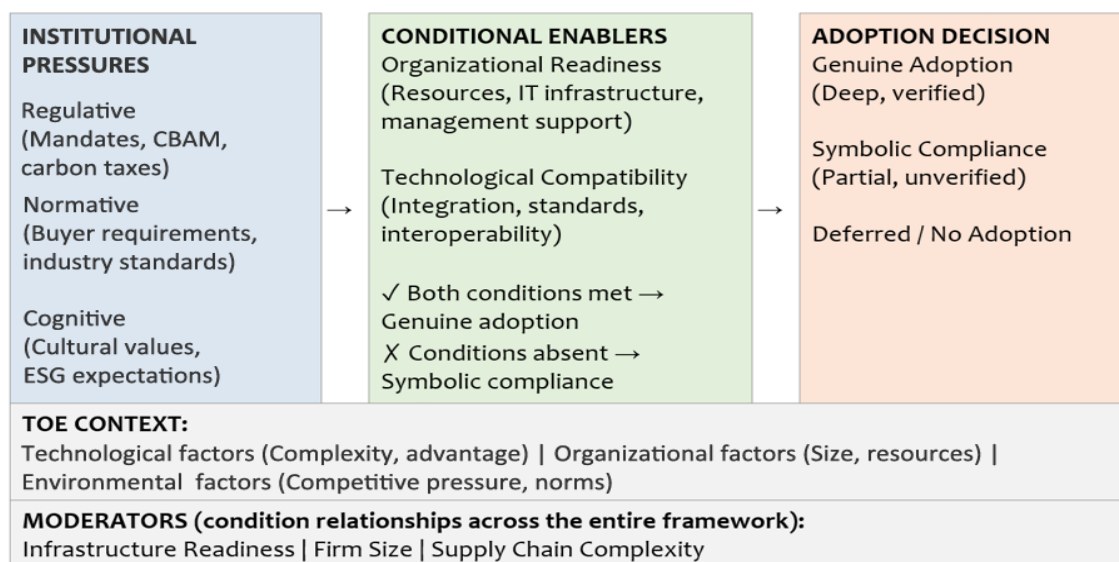


Figure 1: Institutional-Technological Framework for Carbon Footprint Tracking Adoption in ASEAN Cross-Border Supply Chains

Note: Arrows denote directional influence. Both organizational readiness and technological compatibility are conditional enablers: in order for the adoption to occur, the institutional pressure and appropriate enabler conditions have to be activated; if the former is absent, the pressure generates only symbolic adoption. Moderators (infrastructure readiness, firm size, supply chain complexity) determine the strength of the pressure-enabler relationship in the wider ASEAN context.

Institutional Pressures: Distinct Mechanisms, Distinct Predictions

First, the regulative, normative, and cognitive pressures are modeled as three theoretically separate dimensions, rather than as interchangeable proxies for a general “institutional environment.” Accordingly, we expect different effects. Regulative pressures tied to legal requirements, carbon fees, and trade instruments such as CBAM exert adoption pressure calibrated to the credibility of enforcement and the severity of punitive measures. Since ASEAN enforcement capacity diverges dramatically between member states, formally identical policies are likely to produce different outcomes: a carbon fee in a low-enforcement context such as Indonesia exerts minimal practical pressure due to weak implementation capacity, while Singapore’s carbon tax backed by credible regulatory institutions generates significant compliance effects (ASEAN Secretariat, 2021; Delmas & Toffel, 2008).

Normative pressures from multinational customers, industry forums, and certifying agencies operate through contractual and reputation effects. Failing to meet the norms of the suppliers’ buyers with respect to carbon disclosure may result in losing their preferred supplier status, and in the case of export-driven ASEAN economies mean loss of revenue (Busse et al., 2016). As normative pressure does not depend on a state’s enforcement power, Vietnamese and Singaporean electronics makers alike are governed by the same buyer scorecard requirements. This makes normative pressure the most persistent institutional force in the ASEAN region, consistent with evidence that specific buyer requirements are the key trigger for actual implementation in export-driven economies such as Malaysia, Thailand, and Vietnam (Asian Development Bank, 2024).

Cognitive pressures are mediated through accepted organizational norms of appropriate action: the taken-for-granted assumptions decision-makers hold about what a responsible and competitive firm will do. When sustainability becomes part of the taken-for-granted organizational identity (and this is increasingly true of large firms in Singapore and foreign-invested manufacturers in Vietnam), the practice of carbon tracking becomes a constitutive element of firm identity rather than a legal obligation (Husted & de Sousa-Filho, 2017; Scott, 2014). While the most elusive to establish empirically, cognitive pressure produces the deepest and most enduring adoption outcomes, as truly committed firms are more likely to develop multi-stage tracking tools than to settle for a minimum-viable compliance fix.

Conditional Enablers: Organizational Readiness and Technological Compatibility

The most significant theoretical innovation of the framework is the reconceptualization of organizational readiness and technological compatibility as conditional enablers rather than as independent predictors or as mediators. This is more than a terminological nuance. Mediation predicts a causal chain from institutional pressure to readiness to adoption; conditional enablement suggests only that institutional pressure leads to a willingness or motivation to adopt, which precipitates adoption only when the instrumental, structural, and contextual conditions for readiness and compatibility are present. Absent these conditions, there is a gap between motivation and action. This gap is filled by symbolic compliance through public statements, sustainability commitments, or modest levels of partial implementation chosen to address legitimacy demands at minimal cost (Delmas & Toffel, 2008; Greenwood et al., 2011).

Organizational readiness requires financial, IT, and human resources with sustainability competencies, and top management’s strategic emphasis on carbon transparency as a genuine priority (Tornatzky et al., 1990). Technological compatibility refers to the extent to which carbon tracking solutions integrate with existing enterprise systems, align with supply chain partners’ IT infrastructure, and conform to the data standards specified by buyers and government regulators (Oliveira & Martins, 2011). In the ASEAN context, both conditions are systematically absent in SMEs and in less digitally advanced member states, creating a structural adoption gap that persists even under strong institutional pressure. Beyond stating these conditions as conditional enablers, these factors need to be differentiated from the mediators and moderators, as they yield different theoretical predictions. As a mediator, conditions would lead to the occurrence of adoption following institutional pressure, suggesting that institutional pressure causes adoption through the improvement of organizational capability, which then causes adoption. As a moderator, the results of the institutional pressure on adoption will be moderated by the conditions that influence the strength of the relationship. As a conditional enabler, in the absence of the enabling condition, institutional pressure—

regardless of its strength will not by itself produce adoption; it will instead produce symbolic compliance. Conceptually and theoretically distinguishing the conditional enabler from mediators and moderators, Figure 1 positions it as a necessary but insufficient condition between institutional pressure and adoption, such that institutional pressure alone cannot produce adoption without it. This is clearly distinct from a standard moderator, which would say only that the strength of the institutional-pressure-to-adoption relationship depends on the condition's level. It also differs from a mediator, which would say that institutional pressure causes improved organizational capacity, which then causes adoption.

Propositions

The following eight propositions are derived from the framework logic. Propositions P1 through P3 involve the direct effect of institution pressure on adoption, while propositions P4 and P5 describe the conditions under which such an enabling effect occurs. Propositions P6 through P8 involve the moderating effects. They provide predictions that cannot be derived from either TOE or institutional theory on its own.

P1: It is hypothesized that regulatory pressure will exert a positive influence on carbon tracking adoption, conditional on the strength of enforcement: the influence will be more pronounced in ASEAN member states with sustained enforcement capacity, and weaker in states where regulatory mandates lack adequate implementation mechanisms; as a result, formally identical requirements may trigger disparate levels of adoption.

The enforcement-contingency moves P1 beyond a simple positive association by accounting for the observed gap in adoption levels between Singapore, where robust enforcement of carbon regulation drives high adoption and other states with formally similar but weakly enforced legislation (ASEAN Secretariat, 2021; Scott, 2014). This yields a testable hypothesis: firms in states with high regulatory stringency but low enforcement capacity should show adoption rates no higher than firms in states with moderate regulatory stringency but high enforcement capacity.

P2: Multinational buyer-driven normative pressure is hypothesized to be the principal institutional impetus behind carbon tracking adoption by export-oriented ASEAN subsidiaries, and is hypothesized to be independent of domestic regulatory strength, such that subsidiaries in global value chains will have higher rates of adoption than those operating solely within their domestic markets despite possessing similar domestic regulatory requirements.

This proposition explains the empirical regularity that buyer requirements are more effective than domestic standards at inducing adoption in the import-competing sectors of ASEAN (Asian Development Bank, 2024). The independence hypothesis that normative influence and regulatory influence operate through two different mechanisms is a theoretically distinguishable and empirically testable argument, which can be established by comparing the incidence of adoption in export-oriented versus domestic-market firms within the same regulatory context.

P3: Cognitive pressure is hypothesized to influence adoption depth rather than adoption incidence: firms under heavy cognitive pressure would be inclined to implement maximum-viable multi-tier carbon accounting approaches, while firms responding mainly to regulative or normative pressure would tend to adopt minimal-viable compliant approaches, regardless of overall adoption incidence.

This proposition introduces a distinction between adoption incidence—the question of whether a firm adopts at all—and adoption depth, which captures the extent and verifiability of what is implemented. It predicts that research capturing adoption as a yes-no variable will underestimate the signal of cognitive pressure, whereas research capturing the quality of adoption (and thus implicitly capturing the effect of cognitive pressure) will label cognitive pressure as the strongest predictor—a state of affairs with serious consequences for research and policy.

P4: Organizational readiness is hypothesized to act as a conditional enabler of the regulative-pressure-to-adoption relationship: high organizational readiness allows regulative pressure to translate into adoption, whereas low organizational readiness means identical regulative pressures lead instead to third-party certification substitution, symbolic compliance (partial adoption), or voluntary disclosure without verifiable tracking.

This proposition formalizes the conditional logic of enablement for the regulative-adoption nexus. It anticipates an interaction effect rather than a main effect, and suggests that symbolic compliance is the minimum-cost response available to a capacity-constrained firm seeking to meet legitimacy requirements it cannot substantively fulfill. This leads to the empirical prediction that binary measures of adoption in surveys will overstate real adoption in sectors that are dominated by SMEs.

P5: Technological compatibility is a conditional enabler that moderates whether normative pressure actually translates into adoption: where carbon tracking systems are compatible with enterprise and supply chain partner applications and infrastructure, normative pressure translates efficiently into adoption; where compatibility is low, normative pressure correlates with a long evaluation cycle and high levels of deferral and abandonment of adoption, especially for firms with no dedicated IT function.

This proposition identifies how asymmetries in ASEAN's digital infrastructure translate into cost-independent adoption obstacles. Incompatible legacy configurations create a qualitatively different constraint for a highly motivated firm with low technological compatibility than for one with high compatibility. This implication directly informs supplier enablement program design: capability investments must be made prior to or along with normative pressure to facilitate adoption rather than delay it.

P6: Cognitive pressure should have a bigger influence on depth of adoption in sectors for which carbon tracking brings about some tangible competitive advantage (e.g., electronics, automotive, or consumer goods sectors that are under high scrutiny from Environmental, Social, and Governance (ESG)-focused investors) than in sectors for which carbon transparency is seen to be a cost without market premium (commodity sectors), implying that the influence of cognitive pressure on depth of adoption is sector-specific, rather than generic.

This proposition posits a missing boundary condition of cognitive pressure not delineated in earlier work. Competitive differentiation—firms investing heavily in carbon footprinting because of the credible ESG assurances it allows them to offer investors or customers—is only credible in industries where a premium is associated with good ESG performance. In commodity industries where ESG performance does not command a differentiated price, this cognitive pressure may necessarily result in only superficial adoption of practices consistent with industry norms, not the deep investments that genuine belief engenders.

P7: It is hypothesized that infrastructure readiness will have a positive moderating effect on all three institutional pressures and adoption relationships such that for any level of institutional pressure, the incremental effect of an additional unit of institutional pressure on the probability of adoption will be greater in high-infrastructure contexts than in low-infrastructure contexts. Alternatively, institutional pressure may have no statistically significant effect on adoption at any level when infrastructure readiness is extremely low.

The second element of the proposition predicting a null institutional-pressure effect under infrastructure deficits is a less obvious prediction that sets the framework apart from other work. It would suggest that strengthening institutions in ASEAN economies with below-threshold infrastructure would have no effect on adoption unless accompanied by digital infrastructure investment.

P8: Supply chain complexity is hypothesized to positively moderate the relationship between institutional pressures and adoption depth, such that firms downstream in complex multi-tier, cross-border supply chains are more sensitive to all three types of institutional pressure than firms downstream in simpler bilateral supply relationships because the visibility and coordination benefits derived from carbon tracking increase proportionally with supply chain complexity.

This proposition links the technology-adoption benefits literature back to institutional-pressure mechanisms: more complex supply chains increase the value of carbon tracking adoption (perceived relative advantage), while the greater visibility of non-compliance heightens normative and regulative pressure. This combination is why large multinational anchor firms in ASEAN's automotive/electronics industries have seen adoption rates orders of magnitude higher than their respective domestically-oriented counterparts in markets with similar institutions.

Illustrative Cross-Country Comparisons

Table 1 applies the framework to three example ASEAN countries to serve as an illustration of the mechanisms by which the framework may generate country-specific adoption predictions. The cross-sectional comparison

highlights the framework's capability to distinguish between potential country adoption paths that could not be differentiated by a framework defining only one institutional dimension.

Table 1: Institutional and Structural Conditions Shaping Adoption Pathways in ASEAN

Dimension	Singapore	Vietnam	Indonesia
Regulative pressure	High: Mandatory climate reporting for SGX-listed firms; carbon tax raised from S\$5/tCO ₂ e (2019–2023) to S\$25/tCO ₂ e (2024–2025) and S\$45/tCO ₂ e (2026–2027)	Moderate: Green Growth Strategy; voluntary SME guidelines; CBAM exposure	Emerging: Presidential Regulation No. 98/2021 on Carbon Economic Value superseded by PR No. 110/2025; enforcement remains uneven
Infrastructure readiness	High: Advanced digital infrastructure; interoperable trade data platforms	Medium: Strong industrial-zone connectivity; SME gaps persist	Low–Medium: Fragmented digital systems; archipelagic logistics challenges
SME dominance	Low: MNC-led supply chains	High: SMEs >60% of exporters	High: SMEs >70% of firms
Implication for P7	Strong amplification of regulative pressure	Moderation varies by region and sector	Weak amplification due to infrastructure gaps
Implication for P8	Low complexity; normative pressure dominates	High complexity in electronics/textiles; cognitive pressures amplified	Very high complexity; adoption constrained by infrastructure

Source: Synthesized from ASEAN Secretariat (2021); Asian Development Bank (2024); International Telecommunication Union (2022) and OECD (2023).

DISCUSSION

The Institutional-Technological Framework yields three insights that would not be predicted by either TOE or institutional theory alone. This section develops these insights, discusses the tensions found in the extant literature, and allows us to analyze the conditions under which the framework's predictions will be most likely to be either confirmed or refuted.

Why Institutional Pressure Frequently Fails to Produce Adoption

The most important contribution of this framework lies in the ability to elucidate a key phenomenon infrequently elaborated by previous models: why firms facing strong institutional pressure—strong buyer requirements, tight regulation, clear societal norms—are still not adopting carbon tracking. The conditional enablement provides an exact answer: institutional pressure generates adoption motivation but not adoption capacity. In the absence of organizational readiness and technological compatibility, the resulting gap between motivation and action is filled by symbolic compliance rather than actual practice (Delmas & Toffel, 2008).

This has an important methodological implication. Empirical work that proxies adoption as a dichotomous variable (e.g., at the individual firm level, the implementation of the policy of interest) will conflate discrete adopters with symbolic compliers in estimating the institutional pressure effect (P₃), and will induce an upward bias in that estimate. Empirical work that distinguishes breadth of adoption subdimensions (e.g., proportion of tiers with system certification, supply chain tiers covered, second-party/third-party assurance) will be better targeted to estimate the conditional enabling effects described in P₄ and P₅. The framework thus provides a methodological hypothesis in addition to the substantive hypotheses.

The stakes are particularly high in ASEAN's SME-heavy supply chains. For policymakers and buyers who rely on institutional levers without attending to organizational capability, the likely outcome is a landscape of symbolic compliance: firms formally reporting emissions data of uncertain quality, satisfying surface-level

legitimacy demands while producing neither genuine emissions insight nor meaningful supply chain traceability.

The Normative Dominance Paradox and its Limits

The framework's hypothesis P2 that multinational buyers' normative pressure is the primary inducing force of ASEAN adoption incidence is supported by Malaysian, Thai, and Vietnamese empirical evidence (Asian Development Bank, 2024). Nevertheless, the framework anticipates that normative pressure produces shallow rather than comprehensive transparency (P3). It offers a paradox to supply chain sustainability governance: the most successful trigger of adoption, normative buyer pressure, appears as the least reliable trigger to generate independent and comprehensive disaggregated emissions data required by the buyers and regulators.

This pattern is more nuanced than it first appears. The key difference is between norms of pressure that designate an already-defined minimum level of disclosure, and norms of pressure that denote a level of performance that must be verified and subject to audit. Buyer scorecards that call for self-reported, unsupported emissions disclosures set normative incentives for symbolic compliance. Buyer scorecards that call for ISO 14064-verified Scope 3 data—a process increasingly enabled by digital carbon accounting platforms that automate Scope 3 supplier data collection (Hettler & Graf-Vlachy, 2024)—set normative incentives more akin to cognitive pressure, whereby firms need to understand and control their emissions in order to attain trustworthy, verified data. This implies that as buyer requirements shift toward verification standards, this trend may have a stronger effect on adoption depth than the strengthening of domestic regulation, particularly in environments where the latter remains weak.

Infrastructure as a Threshold Rather Than a Gradient

The framework's prediction in P7—that infrastructure readiness has a threshold effect, below which institutional pressure produces no significant effect regardless of its intensity—has a theoretical counterpart in the literature on innovation adoption in terms of “requisite variety” (Tornatzky et al., 1990) and in organizational ecology's concept of environmental carrying capacity (Hannan & Freeman, 1989).

If infrastructure readiness has a threshold effect, marginal investments in regulatory strengthening produce smaller returns in infrastructure-deficient environments than equivalent investments in digital infrastructure. This suggests an optimal policy sequence: infrastructure investment first, followed by regulatory strengthening, rather than the reverse sequence many ASEAN governments have pursued. The model thus generates a policy prescription that challenges common practice and is testable using panel analysis of adoption rates across countries that followed different policy sequences.

Theoretical Implications

What our framework extends to TOE theory is the placement of the three legitimation-seeking processes—coercive, normative, and cognitive isomorphism—within the environmental factors dimension, where the undifferentiated force of “environmental pressure” is replaced by a theoretically grounded taxonomy of institutional pressures. P1–P3 derived from this extension thus enable the formulation of testable hypotheses that specify both the varied response of specific types of firms and organizations as a result of varied pressures, and the differential outcomes of genuine versus symbolic adoption (P4, P5). More importantly, by introducing moderators (P7, P8) that regulate the magnitude of the effects of TOE's environmental components, our proposed framework overcomes the problems of TOE's generalizability in cross-national and cross-cultural research (Oliveira & Martins, 2011; Tornatzky et al., 1990).

The framework makes a contribution to institutional theory by identifying the organizational and technological factors under which institutional pressure induces behavior rather than a symbolic response. This provides a response to a fundamental lacuna of institutional theory, which is rich on the causes of pressure but sparse on the conditions for compliance (DiMaggio & Powell, 1983; Greenwood et al., 2011; Scott, 2014). The location of the conditions in the organization's preparedness to act and in the fit between the technology and

the established work systems, as opposed to strategy and political competence, makes the framework more empirically amenable to predictions that are testable in supply chain and technology management studies.

Managerial Implications

The framework suggests three areas of emphasis for managers in ASEAN supply chains. First, the conditional enablement logic implies that investment in organizational readiness—IT infrastructure, sustainability knowledge, and data governance frameworks—should precede or accompany, rather than follow, responsiveness to institutional pressures. Firms that develop these capabilities ahead of demand are better able to convert buyer requirements into deep adoption rather than symbolic compliance, shifting the adoption framing from cost control to competitive positioning (Golini et al., 2014).

Second, the normative dominance logic implies that another powerful institutional channel working in favor of ASEAN-based suppliers is proactive engagement with buyer requirements. Suppliers satisfying buyer carbon disclosure requirements proactively (and having non-self-reported verified and auditable data to back them up) will, in the long run, gain a position much more difficult for symbolic compliers to replicate. This further points to the need to invest in third-party verification capacity, rather than measurement infrastructure alone, in order to benefit from the market returns driven by normative logic (Busse et al., 2016; Golini et al., 2014).

Third, as the enablement barrier is conditional for SMEs, it can be addressed through industry consortia or buyer-sponsored enablement programs offering common digital infrastructure, pre-coded templates for carbon calculation, and group validation processes. The emerging model of buyer-supervised manufacturer digitalization in the Indonesian textile industry exemplifies such a pathway and offers a scalable solution to the normative dominance paradox (OECD, 2023).

Policy Implications

For ASEAN policymakers, this framework yields several subtle but potentially consequential policy implications. The threshold infrastructure effect (P7) suggests that regionwide regulatory carbon requirements (in order to overcome the digital deficiency of certain members) might be counterproductive if demands for legitimacy outweigh the provision of member capacities, catalyzing the downward spiral of symbolic compliance that erodes the region's ultimate credibility. ASEAN regional organizations such as ASEAN Secretariat and ADB should thus explicitly treat shared digital public goods—interoperable emissions registries, standardized data protocols, and SME-accessible cloud platforms—as preconditions for effective carbon infrastructure regulation, not as an optional complement.

Enforcement-contingency analyses (P1) also suggest that formal compliance with regulatory standards by member states—often heralded as the primary policy remedy for ASEAN's carbon governance fragmentation—may not necessarily inform effective regional governance mechanisms, unless enforcement capacity is aligned across nations. Mutual recognition arrangements for firms to meet the standards of several states through one verified reporting process could be the means to diminish administrative burden without jeopardizing enforcement effectiveness.

Toward Empirical Testing: Suggested Operationalization

The eight propositions outlined thus far are both falsifiable and testable. Table 2 offers initial operationalizations of central constructs of the framework, and could serve as starting points for future survey-based and mixed methods research.

As they are only indicative rather than comprehensive, additional measures should be identified through appropriate scale development processes for ASEAN firms. Indeed, the operationalization shown here differentiates between adoption incidence and adoption depth, while also identifying symbolic compliance as a distinct outcome, since, within the framework, adoption under institutional pressure despite capacity constraints represents an inclination toward symbolic adoption.

Table 2: Suggested Operationalization of Framework Constructs

Construct	Dimension	Potential Measure
Regulative pressure	Coercive	Perceived stringency and enforcement credibility of domestic carbon reporting mandates; adapted from regulatory pressure scales (Sarkis et al., 2010)
Normative pressure	Normative	Buyer carbon disclosure requirements; frequency and specificity of sustainability scorecards from key customers (Golini et al., 2014)
Cognitive pressure	Cognitive	Managerial sustainability orientation; organizational identity alignment with environmental stewardship values (Husted & de Sousa-Filho, 2017)
Organizational readiness	Conditional enabler	IT infrastructure adequacy; financial slack for sustainability investment; dedicated sustainability personnel (Luthra et al., 2022)
Technological compatibility	Conditional enabler	Perceived compatibility of carbon tracking systems with existing ERP/SCM platforms; supply chain partner system interoperability (Oliveira & Martins, 2011)
Infrastructure readiness	Moderator	ITU connectivity indicators; availability of cloud-based carbon accounting platforms in the local market (International Telecommunication Union, 2022)
Supply chain complexity	Moderator	Number of active supplier tiers; geographic dispersion of supply base; percentage of cross-border transactions (Kouhizadeh et al., 2021)
Adoption incidence	Outcome	Binary adoption of any carbon tracking system (yes/no)
Adoption depth	Outcome	Number of supply chain tiers covered; third-party verification status; Scope 3 reporting capability
Symbolic compliance	Outcome	Gap between reported adoption and verified implementation; reliance on self-reported versus audited emissions data (Delmas & Toffel, 2008)

Note: Measures are indicative and should be refined through scale development. Sources indicate prior scales from which items may be adapted.

LIMITATIONS AND FUTURE RESEARCH

This study has several limitations that simultaneously delimit its achievements and provide threads of inquiry for future research efforts. Because this contribution is conceptual and non-empirical, the research framework's propositions have not been empirically tested (design choice: developing a theoretically consistent and falsifiable framework provides a necessary foundation for empirical tests in an understudied cross-border environment). More generally, empirical testing is necessary for the research framework's propositions, especially its conditional enabling effects (P4, P5). Because genuine and symbolic adoption are difficult to distinguish using self-report measures, standard survey methodologies will not reliably distinguish the two; firms' reporting of such adoption will likewise be poor discriminators. The research framework calls for the design of multi-item scales for adoption depth and symbolic compliance that can be adapted for cross-national surveys, supplemented by buyer-side confirmation of supplier adoption quality.

The infrastructure threshold effect suggested in P7 also calls for panel data with enough variation within and between countries in infrastructure investment to identify threshold effects. No cross-sectional adoption studies can do this test at present. Researchers who have access to administrative data from ASEAN trade or environmental agencies, in addition to ITU connectivity measures, have the opportunity to build such a panel data set.

The model emphasizes adoption decisions and depth of adoption as the key adoption outcomes. Subsequent work should consider adoption outcomes: whether the carbon tracking investment actually provided the emissions reductions, supply chain visibility enhancements, and ESG financing access that prompted further adoption initially. If symbolic compliance is widespread under capacity constraints, then the total emissions mitigation achieved by ASEAN-based carbon tracking schemes may be far less substantial than aggregate adoption figures imply—an important consideration for evaluating the success of regional sustainability initiatives (Delmas & Toffel, 2008).

Finally, although the ASEAN context offers a theoretically fertile setting to build the framework, the boundary conditions of the framework should be tested by comparing it with other institutional environments with high heterogeneity and SME dominance, such as South Asian or Sub-Saharan African manufacturing regions. These analogies could identify which characteristics of fragmentation are specific to ASEAN's regional mix of regulatory, digital, and global value chain (GVC) linkage regimes, and which are more generalizable.

CONCLUSIONS

This paper proposes an Institutional-Technological Framework to understand the adoption processes of carbon footprint tracking in ASEAN cross-border supply chains. Its central theoretical contribution is the reconceptualization of organizational readiness and technological compatibility as conditional enablers, rather than as independent predictors or as mediators—a reframing that explains why the rapid strengthening of institutional pressure in developing-country contexts does not automatically translate into adoption, and why the dominant observable outcome in resource-constrained, SME-led supply chains tends to be symbolic compliance rather than genuine carbon tracking capability. As a conceptual contribution awaiting empirical testing, the framework's propositions should be validated by future studies drawing on broader cross-national data and more precise measures capable of distinguishing symbolic from genuine adoption.

Eight propositions extend the predictions of both the TOE and institutional theory frameworks. Three propositions of particular theoretical interest are: (1) that normative pressure primarily influences the incidence, but not the depth, of adoption of export-oriented ASEAN supply chains (P2, P3); (2) that regulative pressure has minimal impact below a critical infrastructure readiness threshold (P7); and (3) that cognitive pressure predicts the depth, but not the incidence, of adoption within sectoral boundaries (P3, P6). These propositions yield falsifiable implications distinct from those of other studies, with clear consequences for research, policymaking, and managerial action.

In terms of practical applications, the framework conceptualizes the investment required in organizational preparedness and digital infrastructure as a “must-have”—not just a “nice-to-have”—by which regulatory and buyer pressure incentivizes real adoption rather than symbolic compliance. As increasing global carbon-disclosure requirements and CBAM-related trade pressures drive ASEAN exporters to seek more verifiable measures of carbon transparency, the difference between genuine and symbolic adoption takes on commercial significance rather than remaining merely an academic curiosity. Testing the framework's hypotheses through future empirical research among ASEAN member states will help identify which policy measures and organizational practices best translate institutional pressures into scalable, verifiable carbon disclosure.

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