

Modeling Digital and Sustainable Innovation Pathways in Tijuana's Business Ecosystem

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Abstract– *In the context of accelerating digitalization and increasing sustainability pressures, firm's ability to simultaneously advance Digital Transformation (DT) and Sustainable Transformation (ST)- referred to as dual transformation- has become a critical determinant of competitiveness, resilience and inclusive development. However, empirical evidence on how these processes jointly unfold within emerging and border-region economies remains limited. This study develops and applies a Dual Transformation Maturity Index (DTMI) to assess firm-level readiness across 148 companies operating in Tijuana, Mexico. Using a structured self-diagnosis instrument, the analysis examines differences in dual transformation maturity by firm, size, sector, export status, certification, and organizational responsibility levels. Results show that, on average, sustainability transformation maturity slightly exceeds digital transformation maturity, revealing uneven capability development across dimensions. Significant heterogeneity is observed, with mid-sized and non-exporting firms exhibiting higher overall maturity, while exporting, large and formally certified firms tend to cluster at lower maturity levels. These findings suggest that dual transformation is shaped less by formal compliance and internal exposure, and more by internal capabilities, governance structures and strategic autonomy. By providing an empirically grounded and context-sensitive maturity framework, this study contributes to innovation systems and dual transformation literature, while offering actionable insights for policymakers and managers seeking to foster integrated and sustainable transformation pathways in emerging economies.*

Keywords– *dual transformation maturity index, digital transformation, sustainable transformation.*

I. INTRODUCTION

Business ecosystems are increasingly shaped by continuous and overlapping transformation pressures. The industrial sector is undergoing rapid digitalization, a process significantly accelerated by the COVID-19 pandemic and intensified by global competition, supply-chain reconfiguration, and evolving communications demands [1]. Digital transformation (DT) has thus shifted from a discretionary technological opportunity to a strategic necessity for organizational survival, efficiency and competitiveness. Firms that adopt digital strategies more rapidly and systematically tend to demonstrate greater adaptability and sustained competitive positioning [2].

Concurrently, these transformations unfold within a context of widening social inequalities and increasing environmental constraints. Firms face mounting pressures, from regulators, markets, consumers, and global value chains, to integrate sustainability principles into their operations [3]. Sustainable transformation (ST) requires long-term commitments that embed environmental stewardship and

social responsibility into organizational strategies, governance structures and value [4]. As a result, sustainability has evolved from a peripheral concern to a core dimension of firm strategy and legitimacy.

Within this context, the simultaneous pursuit of digital transformation (DT) and sustainable transformation (ST), referred to as dual transformation, has emerged as a critical pathway for competitiveness, resilience, and inclusive development [5]. Prior research suggests that integrating DT and ST can generate synergistic value by optimizing resource use, enhancing transparency and governance, and fostering sustainable innovation outcomes [6], [7]. However, empirical evidence indicates that adoption trajectories vary significantly across firms, depending on strategic alignment, leadership engagement, organizational culture, and technological and managerial capabilities [6], [8].

From a theoretical perspective, dual transformation can be interpreted through the lens of the resource-based view (RBV) and dynamic capabilities. RBV posits that sustained competitive advantage derives from the development and deployment of valuable, rare and inimitable resources [21] while the dynamic capabilities perspective emphasizes firms' ability to sense, seize, and reconfigure resources in response to rapidly changing environments [22]. In this sense, dual transformation reflects not only the adoption of technologies or sustainable practices but the development of integrated organizational capabilities that enable firms to align short-term operational demands with long-term strategic objectives.

These challenges are particularly pronounced in emerging and border-region economies such as Tijuana, Mexico, where industrial composition, export orientation, firm heterogeneity, and proximity to cross-border markets shape innovation dynamics and learning pathways. In such ecosystems, firms operate under asymmetric access to resources, infrastructure, and institutional support, influencing both the pace and depth of digital and sustainable transformation.

Despite growing academic attention, most studies continue to examine DT and ST as separate processes, overlooking the integration mechanisms and capability complementarities that characterize dual transformation [10]. This limitation is especially relevant in emergent economies, where contextual and structural constraints condition firms' transformation pathways [11]. Empirical evidence remains scarce regarding how firms of different sizes, sectors, and organizational structures navigate the joint challenges of digitalization and sustainability [12].

In response to this gap, this study aims to model and assess the maturity of dual transformation among 148 firms operating in Tijuana, Mexico, differentiated by size, sector, export status, and managerial responsibility levels. By developing and applying a Dual Transformation Maturity Index (DTMI), the study provides a structured mapping of transformation readiness within a regional business ecosystem. This contribution advances innovation systems research by offering empirical insights into firm-level learning and capability-building processes and supports innovation, and policy-oriented strategies aligned with sustainable development objectives in emerging and cross-border contexts.

II. LITERATURE REVIEW

Digital transformation (DT) refers to the process through which organizations strategically leverage digital technologies to modify operational processes, value creation mechanisms and organizational structures in response to changing business environments [13], [14]. As firms advance along their digital transformation trajectories, they increasingly rely on data-driven decision-making, connectivity, and automation to reconfigure business models and enhance competitiveness.

Sustainable transformation (ST), in contrast, involves the systemic integration of economic, environmental and social objectives into organizational strategies, governance structures and operational practices [15]. Beyond incremental sustainability initiatives, ST represents a fundamental shift in organizational purpose, requiring firms to align long-term value creation with environmental stewardship and social responsibility.

An expanding body of literature highlights the growing interdependence between DT and ST. Digital technologies, such as data analytics, automation, and business intelligence systems, particularly where technological innovation enables improvements in resource efficiency, traceability and environmental performance [16], [17], [18]. As a result, sustainability is increasingly addressed not as an isolated objective but as a process intertwined with digitalization, giving rise to the concept of dual transformation, also referred to as the twin transition [5], [18], [19].

From a theoretical perspective, the integration of DT and ST can be understood through the resource-based view (RBV) and the dynamic capabilities framework. RBV posits that firms achieve sustained competitive advantage through the development and deployment of valuable, rare, inimitable and non-substitutable (VRIN) resources [21]. In the context of dual transformation, digital capabilities and sustainability capabilities can be conceptualized as strategic resources that underpin competitive positioning.

Extending this perspective, the dynamic capabilities framework emphasizes firms' ability to sense emerging technological and sustainability opportunities, seize them through strategic alignment, and reconfigure internal resources accordingly [22]. Dual transformation therefore represents not only the accumulation of digital and sustainability-related

assets but also the organizational capacity to integrate, adapt, and continuously renew these capabilities in response to environmental complexity.

Recent systemic literature reviews have mapped the rapid expansion of research at the intersection of digitalization and sustainability. [8] reviewing more than 1300 academic articles, identifying key thematic overlaps, technological enablers, and organizational challenges associated with dual transformation, particularly among small and medium-sized enterprises. Related reviews highlight both opportunities and structural constraints, while consistently calling for more integrative frameworks capable of synthesizing digital and sustainable transformation processes [19], [23], [24].

The integrated pursuit of DT and ST is commonly referred to as dual transformation of twin transition, emphasizing their mutually reinforcing nature within organizations [5], [18], [19], [20]. At the policy level, this integration is reflected in initiatives such as the European Green Deal, which explicitly promotes the simultaneous advancement of digital and environmental transitions to enhance economic competitiveness, resilience, and social inclusion [5]. From a theoretical standpoint, the resource-based view (RBV) suggests that sustained competitive advantage arises from the development and strategic deployment of valuable, rare, and inimitable internal resources and capabilities [21]. Extending this logic, the dynamic capabilities perspective emphasizes firms' ability to sense technological and sustainability-related opportunities, seize them through strategic integration, and continuously reconfigure organizational resources in response to environmental change [22].

Despite these advances, empirical operationalization of dual transformation remains fragmented, limiting comparability across firms and regions. Existing studies often analyse DT and ST separately, overlooking the capability complementarities and governance mechanisms required for their integration. This gap is particularly pronounced in emerging and border-region economies, where institutional constraints, resource asymmetries, and heterogeneous firm structures shape transformation pathways [10], [11], [12].

To address this gap, the present study proposes the Dual Transformation Maturity Index (DTMI) as a composite measurement instrument and the Dual Transformation Pathways (DTP) framework as an interpretive model.

The DTMI is derived from 24 items capturing two complementary pillars, Digital Transformation (DT) and Sustainable Transformation (ST) and enables benchmarking across firms with different sizes, sectors, and organizational profiles. Building on existing transformation typologies, the DTP framework classifies firms into four strategic quadrants:

- Laggards (low-low): organizations exhibiting below-average maturity in both DT and ST, reflecting limited progress in dual transformation

- Sustainable-first: firms with above-average ST but below-average DT, characterized by advance sustainability practices alongside lagging digital adoption
- Digital-first: organizations with above-average DT but below-average ST, typically prioritizing digitalization while underinvesting in sustainability initiatives.
- Integrated: enterprises demonstrating balanced and advanced maturity across both dimensions, achieving synergies between technological adoption and sustainability outcomes.

Empirical evidence suggests that firms capable of aligning DT and ST strategies tend to achieve higher levels of competitiveness, resilience, and long-term performance [25]. However, empirical applications of dual transformation maturity frameworks remain scarce in emerging and cross-border economies. By operationalizing dual transformation maturity within a regional business ecosystem, this study contributes to innovation systems focused on inclusive and sustainable industrial transformation.

III. METHODOLOGY

This study employed a quantitative, non-experimental, cross-sectional design to assess the maturity of Digital Transformation (DT) and Sustainable Transformation (ST), jointly referred to as dual transformation, in firms operating within Tijuana's business ecosystem. This approach enabled the development and application of the Dual Transformation Maturity Index (DTMI) as a diagnostic and benchmarking tool.

A. Data Collection

Data was collected from 148 firms during mid-2023, covering micro, small, medium, and large companies across various sectors and export orientations. A structured self-assessment questionnaire, adapted from validated instruments [6], was administered electronically through industry associations and professional networks. Respondents included decision-makers such as managers and executives.

The survey instrument is grounded in the dual transformation maturity framework previously validated by Encinas et al (2024) [6]. To ensure its reliability within the specificity context of Tijuana's business ecosystems, internal consistency was assessed using Cronbach's alpha(α).

The results indicate high reliability levels for both dimensions, with coefficients of $\alpha = 0.945$ for the Digital Transformation (DT) scale and $\alpha = 0.971$ for the Sustainable Transformation (ST) scale. These values exceed the recommended threshold of 0.70, confirming the robustness of the instrument for this study. The survey covered:

Control variables: sector, size, export status, quality certifications and responsibility level

DT dimension: 12 items on strategy, culture, capabilities, data-driven decision-making, and integration

ST dimension: 12 parallel items aligned to sustainability practices. All items used a five-point Likert scale (1 = strongly disagree; 5 = strongly agree).

B. Data Processing and Analysis

Responses were cleaned and coded for statistical analysis. Likert items were treated as interval data to compute average DT and ST maturity scores per firm. Descriptive statistics (means, standard deviations) were calculated, and comparative analysis was conducted across firm characteristics (e.g., sector, size, quality certifications and export status).

To capture joint transformation patterns, DT and ST scores were combined into the DTMI. Firms were then classified into four strategic pathways: Laggards, Digital-first, Sustainability-first, and Integrated, reflecting their relative positioning across the maturity spectrum.

C. Ethical Considerations

Participation in the study was voluntary and based on informed consent. Respondents were clearly informed about the purpose of the research and the use of the collected data. All responses were treated confidentially and analyzed in aggregated form to ensure the anonymity of both individuals and organizations. The data collected were used exclusively for academic and research purposes.

IV. RESULTS

The study analyzes 148 firms located in Tijuana, Mexico, encompassing heterogeneous sectoral compositions, firm sizes, export orientations, quality certification statuses, and organizational responsibility levels. Digital Transformation (DT) and Sustainable Transformation (ST) maturity scores are examined descriptively to identify structural patterns and differentiated dual transformation pathways within the regional business ecosystem. The sample is dominated by firms operating in the Services sector (57.43%), followed by Manufacturing (15.54%), Wholesale Trade (14.86%), and Retail Trade (12.16%). This distribution reflects the service-oriented structure of Tijuana's economy and provides a relevant basis for comparing transformation maturity across service-based activities and production-related activities.

4.1 Sectoral maturity patterns

Moderate differences in dual transformation maturity emerge across (Table I). Firms operating in Services ($n=84$) report slightly higher average digital maturity ($DT=2.38$) compared to firms in Wholesale and Manufacturing activities ($n=64$; $DT= 2.34$), although this difference is marginal.

In contrast, sustainability maturity is marginally higher among Wholesale firms ($ST= 2.63$) than among Services firms ($ST= 2.60$), suggesting that sustainability-related practices may be somewhat more embedded in production, and distribution, oriented activities.

TABLE I.
DUAL TRANSFORMATION MATURITY BY SECTOR

Sectors	DT_ AVG	Std Dev DT	ST_ AVG	Std Dev ST
Services	2.38	1.02	2.60	1.10
Wholesale and manufacturing	2.34	1.06	2.63	1.11

According to table 1, both sectoral groups exhibit comparable levels of dispersion. Standard deviations for DT (Services = 1.02; Wholesale and Manufacturing = 1.06) and ST (Services = 1.10; Wholesale and Manufacturing = 1.11) indicate substantial intra-sectoral heterogeneity pointing to uneven adoption patterns rather than sector-wide convergence. Overall, both sectors appear positioned at an intermediate stage of transformation, with sustainability maturity slightly outpacing digitalization.

4.2 Firm size

In table II firm size reveals clearer differentiation patterns in dual transformation maturity that sectoral affiliation (table II). Micro firms (0–20 employees) represent 33.11% of the sample, report the highest average digital maturity (DT = 2.53; SD=0.844), suggesting relatively agile and focused digital adoption processes.

Their sustainability maturity is moderate (ST=2.59, SD=1.02) and displays lower dispersion than larger firms, indicating more homogeneous transformation trajectories.

TABLE II
DUAL TRANSFORMATION MATURITY BY FIRM SIZE

Company size	DT_ AVG	Std Dev DT AVG	ST_ AVG	Std Dev ST AVG
Micro firms (0 – 20)	2.53	0.844	2.59	1.02
Mid firms (21 – 50)	2.47	1.06	2.75	1.13
Mid firms (51 – 100)	2.35	1.30	2.74	1.25
Large firms (101 or more)	2.08	1.02	2.42	1.08

Mid-sized firms (21–100 employees), accounting for 39.86% of the sample, exhibit a distinct pattern. They combine relatively strong digital maturity (DT=2.47; SD= 1.06) with the highest sustainability maturity across all size categories (ST = 2.75; SD=1.13).

Firms in the 51-100 employee range maintain high sustainability maturity (ST=2.74) but show declining digital maturity (DT=2.35) and increased variability, pointing to divergent transformation strategies within this group. In contrast, large firms (101+ employees) report the lowest maturity levels DT (2.08) and ST (2.42), despite moderate dispersion. This challenges the conventional assumption that scale facilitates advanced transformation, suggesting instead that organizational complexity, legacy systems and compliance-driven structures may slow both digital and sustainability transition into larger firms.

4.3 Export Status and transformation Performance

Export status emerges as a meaningful differentiator of dual transformation maturity within the Tijuana Business

Ecosystem (table III). Non-exporting firms which constitute 71.62% of the sample, exhibit higher average maturity in both DT (2.5) and ST (2.7) compared to exporting firms (DT = 2.0; ST = 2.3).

TABLE III
DTMI BY EXPORT STATUS

Export status	DT_ AVG	StdDev DT AVG	ST_ AVG	StdDev ST AVG
Non-exporters	2.51	1.05	2.74	1.09
Exporters	2.00	0.883	2.29	1.07

Contrary to conventional assumptions that international market exposure accelerates organizational transformation, the lower DT and ST scores among exporting firms suggest that export orientation in emerging border economies may be driven more by cost efficiency, regulatory compliance and standardized operational routines than by integrated digital and sustainable strategies.

By contrast, non-exporting firms display both higher average maturity and greater variability across DT and ST dimensions, reflecting a broader range of strategic approaches and potentially greater experimentation oriented toward local and regional markets.

4.4 Quality certifications and dual transformation maturity

Quality certifications are present in 38.5% of the firms in the sample, while 61.5% operate without formal certifications. Contrary to conventional expectations, non-certified firms exhibit substantially higher maturity in both transformation dimensions (table IV). Specifically, non-certified firms (DT=2.00; ST=2.18).

TABLE IV
DTMI BY QUALITY CERTIFICATIONS

Quality certifications	DT_ AVG	StdDev DT_AV G	ST_ AVG	StdDev ST_AV G
Nonformal certifications	2.59	0.954	2.88	1.10
Formal certifications	2.00	1.05	2.18	0.947

Non-certified firms also display slightly lower variability in DT, suggesting more consistent digital adoption patterns. This pattern may reflect greater organizational flexibility, autonomy in strategic decision-making and experimentation with digital tools and sustainability practices beyond formal audit requirements. These findings challenge the assumption that quality certification functions as enablers of advanced transformation maturity.

4.5 Organizational Responsibility Level

Dual transformation maturity also varies according to organizational responsibility levels, particularly with respect to digital transformation (table V). Firms where responsibility is assigned to functional management report relatively higher average digital maturity (DT= 2.45), although this is accompanied by substantial variability (SD= 1.24), indicating heterogenous implementation patterns across organizations.

TABLE V
DTMI BY ORGANIZATIONAL ROLE

Organizational Roles	DT_AVG	StdDev DT_AVG	ST_AVG	StdDev ST_AVG
Business Unit Management	1.75	0.500	2.6	1.29
Functional Management	2.45	1.24	2.66	1.42
General Management	2.23	0.912	2.59	0.959
Operational Executives	2.38	0.961	2.46	1.20
Not available	3.33	1.07	2.83	1.19

In contrast, firms where responsibility is located at the business unit management level consistently report the lowest digital maturity (DT= 1.75; SD= 0.50), pointing to limited scope, authority or resource availability to drive organization-wide digital transformation from localized units. General management (DT = 2.23; SD=0.912) and operational executives (DT = 2.38; SD=0.961) exhibit intermediate digital maturity, reflecting more balance but not necessarily leading roles in transformation processes. Across all responsibility levels, sustainable transformation maturity remains relatively stable (approximately 2.6), clustering around average of 2.6 suggesting that sustainability practices are more uniformly communicated and adopted across organizational hierarchies than digital initiatives, which appear more sensitive to internal governance structures and decision-making authority.

4.6 Dual Transformation Maturity Index

Based on the Dual Transformation Maturity Index (DTMI), firms are distributed across four pathways: Laggards, Sustainability-first, Digital-first, and Integrated. Figure 1 illustrates the positioning of firm categories according to their relative DT and ST maturity.

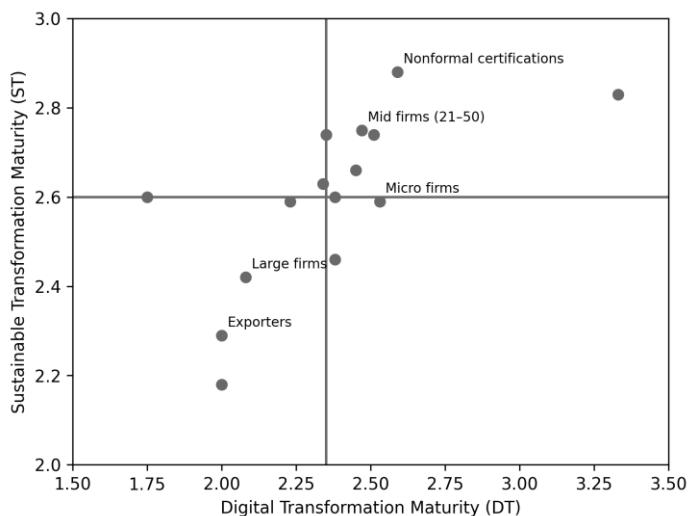


Fig. 1. Dual Transformation Pathways across firm characteristics in Tijuana's Business Ecosystem.

The results show that non-formal certification and mid-sized firms are more likely to position closer to the Integrated or

Sustainability-first quadrants, reflecting strong sustainability maturity combined with moderate-to-high digital capabilities. In contrast, exporting firms, large firms, and certified firms tend to cluster within the laggard's quadrant, exhibiting below-average maturity in both dimensions.

Notably, the digital first pathway is largely absent, indicating that digitalization without a corresponding sustainable orientation is not a dominant transformation strategy within the regional ecosystem. Overall, the finding demonstrates that dual transformation maturity in Tijuana is highly heterogeneous and structurally conditioned. Sustainability practices appear more broadly diffused across firms, while digital transformation remains uneven and clustered. Firm size, export orientation, certification status and organizational responsibility levels collectively shape distinct dual transformation pathways, within the regional business ecosystem.

4.7 Inferential Analysis of Dual Transformation

To enhance analytical rigor beyond descriptive statistics, a simple linear regression analysis (ordinary least squares, OLS) was conducted to examine the extent to which Sustainable Transformation (ST) maturity predicts Digital Transformation (DT) maturity across firms. The model demonstrates a strong and statistically significant relationship between both dimensions. The results indicate a correlation coefficient of $R = 0.692$ and a coefficient of determination $R^2 = 0.479$, suggesting that approximately 47.9% of the variance in digital transformation maturity can be explained by sustainability maturity. The overall model is highly significant ($F(1,146) = 134.10$, $p < .001$), confirming the robustness of the relationship.

TABLE VI.
LINEAR REGRESSION RESULTS FOR DT AND ST MATURITY

Predictor	Estimate	Standard Error	t	p
Intercept	0.942	0.185	5.09	< .001
ST Maturity	0.650	0.056	11.58	< .001

Table VI reports the estimated coefficients for ST maturity ($\beta = 0.650$, $SE = 0.056$, $t = 11.58$, $p < .001$) indicates that a one-unit increase in sustainability maturity is associated with a 0.65 increase in digital transformation maturity. This result provides strong empirical support for the interdependence between sustainability and digitalization processes.

From a theoretical perspective, these findings are consistent with the "twin transition" framework and can be interpreted through the lens of the resource-based view (RBV) and dynamic capabilities. Specifically, sustainability-related practices may function as complementary organizational capabilities that enhance firms' ability to adopt and leverage digital technologies. In this sense, firms that develop sustainability-oriented routines, governance structures, and stakeholder integration mechanisms may simultaneously strengthen their capacity to sense opportunities, mobilize

resources, and reconfigure processes, key elements of dynamic capabilities.

Overall, the results suggest that sustainability transformation is not only an outcome but also a potential driver of digital transformation within emerging and border-region business ecosystems.

5. DISCUSSION

The findings on this study reinforce and extend the growing body of literature on dual transformation, demonstrating that the integration of digital transformation (DT) and sustainable transformation (ST) is neither linear nor uniformly distributed across firms. By applying the Dual Transformation Maturity Index (DTMI) the analysis reveals distinct transformation pathways within Tijuana's business ecosystem, highlighting the critical role of organizational capabilities and contextual conditions in shaping transformation readiness.

From a resource-based view (RBV) perspective, the results suggest that differences in dual transformation maturity are closely associated with the heterogeneity of firm-level resources and capabilities. Firms positioned in integrated or sustainability-first pathways appear to possess more developed bundles of strategic resources, particularly those related to organizational coordination, governance and sustainability-oriented routines. These resources may provide a foundation for building complementary digital capabilities, reinforcing the observed positive relationship between ST and DT maturity identified in the inferential analysis.

The strong predictive relationship between sustainability and digital transformation supports the interpretation of sustainability practices as enabling capabilities rather than merely compliance-driven activities. In RBV terms, sustainability-oriented processes—such as stakeholder integration, environmental management, and long-term strategic alignment—can function as valuable and difficult-to-imitate organizational resources that enhance firms' ability to adopt and scale digital technologies. This finding contributes to the twin transition literature by empirically demonstrating that sustainability transformation can act as a driver of digital transformation within emerging business ecosystems.

Importantly, these results respond to recent observations in the literature calling for a shift beyond diagnostic approaches to dual transformation. As noted by Radtke [26], prior empirical work, particularly Encinas-Grijalva et al. [6], primarily evaluates transformation readiness through aligned organizational dimensions using descriptive and correlational methods, without explicitly examining the interaction between digital and sustainable transformation. By contrast, the present study advances this line of inquiry by providing empirical evidence of a directional relationship, positioning sustainability as a capability that can actively drive digital transformation processes.

Firms positioned closer to integrated or sustainability-first pathways are not those most exposed to international markets or formal certification regimes, but rather firms that retain greater strategic autonomy and internal coordination capacity. In contrast, exporting firms, large firms, and firms operating under certification-heavy regimes consistently cluster within lagging pathways, exhibiting below-average maturity in both digital and sustainability dimensions. This pattern challenges the common assumption that export participation, scale, or formal standards automatically foster advanced transformation outcomes.

The results suggest that, within an emerging border economy, export-oriented firms may prioritize efficiency, standardization and adherence to externally imposed requirements over internal capability development. In such contexts, digital and sustainability initiatives appear more closely aligned with compliance and operational continuity than with organizational learning, experimentation, or strategic integration. This finding aligns with research on compliance-oriented dynamics in global value chains, where firms may meet external benchmarks without developing the deeper capabilities required for transformative innovation.

One of the most salient and counterintuitive findings of the study is that non-exporting firms outperform exporters in both digital and sustainable transformation maturity. While international market participation is often associated with innovation upgrading, the evidence from Tijuana points to a different mechanism. Export-oriented firms may face strong pressures to conform to buyer-imposed standards, reinforcing standardized routines that limit incentives for broader digital experimentation or sustainability-driven innovation. Non-exporters, by contrast, appear to retain greater strategic flexibility, enabling more experimentation, adaptive learning, and the integration of digital and sustainability-oriented initiatives.

Interpreted through a border economy lens, these findings highlight how firms operate at the intersection of global market pressures and local institutional constraints. In regions such as Tijuana, access to innovation infrastructure, policy support, and learning opportunities is uneven, and firms with similar resource endowments may follow markedly different transformation pathways. Under these conditions, governance arrangements, decision-making autonomy, and the ability to align digital and sustainability objectives become more consequential than formal compliance mechanisms.

Finally, the finding that sustainability transformation maturity significantly predicts digital transformation maturity ($R^2 = 0.479$) provides additional support for the RBV and dynamic capabilities perspectives. Firms that have developed the capacity to sense and respond to environmental pressures are more likely to reconfigure their internal processes, making

digitalization a natural extension of their adaptive strategies and organizational evolution.

6. CONCLUSION

This study provides empirical evidence on the maturity of dual transformation, encompassing digital transformation (DT) and sustainable transformation (ST), within the business ecosystem of Tijuana, a strategically significant border-region economy where firms operate under simultaneous global market pressures and local structural constraints. Using a quantitative, descriptive approach, the research introduces the Dual Transformation Maturity Index (DTMI) as a systematic framework for assessing transformation readiness, benchmarking firms, and identifying differentiated transformation pathways across organizational profiles. The results show that sustainable transformation maturity (ST=2.6) slightly exceeds digital transformation maturity (DT=2.4), indicating that firms in Tijuana, Mexico, are on average, more responsive to environmental and social pressures than to digital imperatives. At the same time, substantial dispersion across both dimensions reveals that dual transformation is not advancing uniformly reflecting uneven accumulation of organizational capabilities within the regional ecosystem.

Firm-level characteristics play a decisive role in shaping transformation outcomes. Mid-sized and non-exporting firms exhibit higher overall dual transformation maturity and are more likely to position closer to integrated or sustainability-first pathways. In contrast, export-oriented firms, large firms, and firms operating under formal certification regimes consistently display lower maturity in both DT and ST. These findings challenge the assumption that scale, export participation, or certification automatically foster advanced transformation and instead point to the prevalence of compliance-oriented operating models that may constrain deeper capability development.

From a theoretical perspective, the study contributes to the literature by linking dual transformation with the resource-based view (RBV) and dynamic capabilities framework. The results suggest that sustainability-related practices can function as foundational capabilities that enable digital transformation, reinforcing the concept of the “twin transition” as a process of capability integration rather than parallel or independent developments.

From a practical and policy perspective, the findings highlight the need to shift the focus from compliance and technological adoption toward capability-building, governance flexibility, and strategic alignment. Supporting firms in developing integrative capabilities may be more effective than promoting isolated digital or sustainability initiatives, particularly in emerging and border-region contexts where structural constraints shape transformation opportunities.

Overall, this study advances the understanding of dual transformation by providing an empirically grounded, context-sensitive framework that captures the complexity and heterogeneity of transformation pathways. By doing so, it contributes to ongoing debates on how firms in emerging economies can achieve more integrated, resilient, and sustainable development trajectories.

7. LIMITATIONS AND FUTURE RESEARCH

This study has several limitations that open avenues for future research. First, the analysis is based on a cross-sectional design and primarily descriptive, which limits causal inference and the ability to capture dynamic transformation processes over time. Second, the reliance on self-reported survey data may introduce perceptual bias, suggesting the value of triangulating survey responses with objective indicators or qualitative evidence. Finally, while the DTMI is applied at the firm level, future studies could extend the framework to sectoral, value-chain, or regional innovation system analyses, strengthening its relevance for policy design and comparative research.

Despite these limitations, the study demonstrates that dual transformation in border economies is less about technology adoption or formal compliance and more about organizational learning, governance, and strategic autonomy. By offering a context-sensitive measurement framework and empirical insights from Tijuana, this research contributes to ongoing debates on how innovation can support more inclusive, resilient, and sustainable development in regions operating at the margins of global value chains.

REFERENCES

- [1] S. Kraus, S. Durst, J. J. Ferreira, P. Veiga, N. Kailer, and A. Weinmann, “Digital transformation in business and management research: An overview of the current status quo,” *Int. J. Inf. Manage.*, vol. 63, p. 102466, Apr. 2022, doi: 10.1016/j.ijinfomgt.2021.102466.
- [2] S. Kraus, P. Jones, N. Kailer, A. Weinmann, N. Chaparro-Banegas, and N. Roig-Tierno, “Digital Transformation: An Overview of the Current State of the Art of Research,” *Sage Open*, vol. 11, no. 3, Jul. 2021, doi: 10.1177/21582440211047576.
- [3] L. Broccardo, A. Zicari, F. Jabeen, and Z. A. Bhatti, “How digitalization supports a sustainable business model: A literature review,” *Technol. Forecast. Soc. Change*, vol. 187, p. 122146, Feb. 2023, doi: 10.1016/j.techfore.2022.122146.
- [4] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, “The Circular Economy – A new sustainability paradigm?” *J. Clean. Prod.*, vol. 143, pp. 757–768, Feb. 2017, doi: 10.1016/j.jclepro.2016.12.048.
- [5] B. Shajari and I. David, “Bridging the Silos of Digitalization and Sustainability by Twin Transition: A Multivocal Literature Review,” *Jun. 2025*, [Online]. Available: <http://arxiv.org/abs/2506.04267>
- [6] M. del Socorro Encinas-Grijalva, F. A. Olivieri-Sangiacomo, E. Galván-Vela, and R. Ravina-Ripoll, “Business readiness for dual transformation: an analysis of business capabilities for digital and sustainable transformation,” *Discover Sustainability*, vol. 5, no. 1, Dec. 2024, doi: 10.1007/s43621-024-00370-8.
- [7] I. Guandalini, “Sustainability through digital transformation: A systematic literature review for research guidance,” *J. Bus. Res.*, vol. 148, pp. 456–471, Sep. 2022, doi: 10.1016/j.jbusres.2022.05.003.

- [8] C. Kürpick, A. Kühn, L. Olszewski, and R. Dumitrescu, "Framework for Dual Transformation: A Systematic Literature Review on the Interplays between Digitalization and Sustainability," Aug. 2023, pp. 175–182. doi: 10.1109/SusTech57309.2023.10129630.
- [9] A. Rosales-Soto and R. Arechavala-Vargas, "Technological capabilities and competitiveness in Jalisco's berry export companies," Red Internacional de Investigadores en Competitividad, 2019.
- [10] E. Susanti, R. Y. Mulyanti, and L. N. Wati, "Systematic Literature Review: Increasing Performance of Women MSMEs Through Competitive Advantage Based on Digital Transformation and Innovation," 2023, pp. 25–61. doi: 10.2991/978-94-6463-068-8_4.
- [11] M. Matarazzo, L. Penco, G. Profumo, and R. Quaglia, "Digital transformation and customer value creation in Made in Italy SMEs: A dynamic capabilities perspective," J. Bus. Res., vol. 123, pp. 642–656, Feb. 2021, doi: 10.1016/j.jbusres.2020.10.033.
- [12] E. Ghosh and L. J. Pearson, "Rethinking Economic Foundations for Sustainable Development: A Comprehensive Assessment of Six Economic Paradigms Against the SDGs," Sustainability, vol. 17, no. 10, p. 4567, May 2025, doi: 10.3390/su17104567.
- [13] A. Rosales-Soto, "The era of the metaverse for the digital transformation of businesses," in Digital transformation as a value proposition for competitiveness, 1st ed., vol. 1, University of Guadalajara, Ed., 2022.
- [14] J. H. Puente, "Digital Business Designs in Latin America: A 2025 Literature Review," Netnography, vol. 3, p. 217, Oct. 2025, doi: 10.62486/net2025217.
- [15] Chioma Susan Nwaimo, Ayodeji Enoch Adegbola, and Mayokun Daniel Adegbola, "Sustainable business intelligence solutions: Integrating advanced tools for long-term business growth," GSC Advanced Research and Reviews, vol. 19, no. 3, pp. 031–039, Jun. 2024, doi: 10.30574/gscarr.2024.19.3.0190.
- [16] Z. Ji, T. Zhou, and Q. Zhang, "The Impact of Digital Transformation on Corporate Sustainability: Evidence from Listed Companies in China," Sustainability, vol. 15, no. 3, p. 2117, Jan. 2023, doi: 10.3390/su15032117.
- [17] Y. Song, C. Du, P. Du, R. Liu, and Z. Lu, "Digital transformation and corporate environmental performance: Evidence from Chinese listed companies," Technol. Forecast. Soc. Change, vol. 201, p. 123159, Apr. 2024, doi: 10.1016/j.techfore.2023.123159.
- [18] T. Kilinc, D. Sjödin, and V. Parida, "Navigating Digital Servitization for the Twin Transition: How Manufacturers Can Support Customers with Digitalization and Sustainability," Bus. Strategy Environ., vol. 34, no. 5, pp. 5370–5385, Jul. 2025, doi: 10.1002/bse.4255.
- [19] S. Tabares, V. Parida, and K. Chirumalla, "Twin transition in industrial organizations: Conceptualization, implementation framework, and research agenda," Technol. Forecast. Soc. Change, vol. 213, Apr. 2025, doi: 10.1016/j.techfore.2025.123995.
- [20] I. Siedschlag, G. Mohan, and W. Yan, "Twin Transitions Across Enterprises: Do digital technologies and sustainability go together?," SSRN Electronic Journal, 2024, doi: 10.2139/ssrn.4912063.
- [21] J. Barney, "Firm Resources and Sustained Competitive Advantage," J. Manage., vol. 17, no. 1, pp. 99–120, Mar. 1991, doi: 10.1177/014920639101700108.
- [22] L. Guo, F. Chen, and L. Chen, "How does digital transformation affect corporate sustainability performance? Evidence from listed energy companies in China," PLoS One, vol. 20, no. 6, p. e0325898, Jun. 2025, doi: 10.1371/journal.pone.0325898.
- [23] C. Toşa, C. P. Paneru, A. Joudavi, and A. K. M. Tarigan, "Digital transformation, incentives, and pro-environmental behaviour: Assessing the uptake of sustainability in companies' transition towards circular economy," Sustain. Prod. Consum., vol. 47, pp. 632–643, Jun. 2024, doi: 10.1016/j.spc.2024.04.032.
- [24] C. Kürpick, A. Rasor, M. Scholtysik, A. Kühn, C. Koldewey, and R. Dumitrescu, "An Integrative View of the Transformations towards Sustainability and Digitalization: The Case for a Dual Transformation," in Procedia CIRP, Elsevier B.V., 2023, pp. 614–619. doi: 10.1016/j.procir.2023.02.155.
- [25] H. T. Lu, X. Li, and K. F. Yuen, "Digital transformation as an enabler of sustainability innovation and performance – Information processing and innovation ambidexterity perspectives," Technol. Forecast. Soc. Change, vol. 196, p. 122860, Nov. 2023, doi: 10.1016/j.techfore.2023.122860.
- [26] J. Radtke, "Title of the thesis," Master's thesis, University, City, Country, Year. [Online]. Available: https://epub.uni-bayreuth.de/id/eprint/9011/3/202603_MasterThesis_JohannaRadtke.pdf