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The Role of Carbon Accounting, Digital Transformation, Global Uncertainty, and Energy Efficiency in Improving Financial Decision-Making and Supporting Sustainability in High-Emission Industries

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Abstract

This study aimed to examine the integrated effects of Carbon Accounting (CA), Digital Transformation (DT), Energy Efficiency (EE), and Global Uncertainty (GU) on enhancing Financial Decision-Making Quality (FDMQ) and improving Sustainability Performance (SP) in high-emission industrial companies. Drawing on Dynamic Capabilities Theory, the study proposed that these practices represent interconnected organizational capabilities that enhance firms' adaptive capacity and their ability to create sustainable value, while Global Uncertainty represents a contextual factor that may influence the effectiveness of these capabilities. The study adopted a quantitative longitudinal research design using Panel Data Analysis based on secondary data obtained from annual financial reports, sustainability reports, and corporate disclosures of industrial companies listed on the Palestine Exchange. The sample consisted of ten industrial companies observed over the period 2020–2025, resulting in 59 firm-year observations. The Fixed Effects Model was employed to examine the direct relationships among the study variables, complemented by mediation and moderation analyses to investigate the mediating role of Financial Decision-Making Quality and the moderating effect of Global Uncertainty. The empirical findings revealed that Carbon Accounting, Digital Transformation, and Energy Efficiency positively affect Financial Decision-Making Quality, indicating that firms with more advanced environmental accounting systems, stronger digital capabilities, and higher operational efficiency are better positioned to make effective financial decisions. Furthermore, these organizational capabilities were found to have direct positive effects on Sustainability Performance. In contrast, Global Uncertainty was found to negatively affect both Financial Decision-Making Quality and Sustainability Performance, while also weakening the positive effects of organizational capabilities on financial decision-making. The results further confirmed that Financial Decision-Making Quality plays a significant mediating role in the relationship between organizational capabilities and Sustainability Performance. Overall, the findings support the assumptions of Dynamic Capabilities Theory by demonstrating that achieving sustainability in high-emission industries requires the integration of environmental, digital, and financial capabilities within a coordinated organizational system rather than treating them as isolated practices.



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Keywords: carbon accounting; digital transformation; global uncertainty; energy efficiency; financial performance; sustainability; PLS-SEM; high-emission industries; Palestine Exchange

1. Introduction

Carbon accounting is used to quantify an organization's greenhouse gas emissions based on data collected up until October 2023, particularly in high-emission industries such as energy, manufacturing, and transportation. As climate risks continue to intensify and regulatory frameworks become more stringent—such as the Task Force on Climate-related Financial Disclosures (TCFD) and the European Union's Corporate Sustainability Reporting Directive (CSRD)—organizations are increasingly required to integrate carbon accounting into their financial and strategic decision-making processes. These developments reflect a growing consensus among regulators, investors, and stakeholders that transparent carbon measurement is essential for assessing climate-related financial risks and identifying long-term sustainability opportunities [1,2].

Carbon accounting extends beyond traditional emissions measurement to influence core financial decisions, including capital allocation, investment appraisal, cost management, and risk assessment in high-emission industries. By distinguishing between Scope 1, Scope 2, and Scope 3 emissions, carbon accounting provides a comprehensive data foundation that enables firms to evaluate the financial implications of decarbonization initiatives and develop long-term sustainability strategies [3,4].

Despite its importance, the relationship between carbon accounting and financial decision-making remains complex and not fully consistent in the literature. Some studies suggest that enhanced carbon disclosure improves access to green financing and reduces the cost of capital [5,6], while others indicate that carbon accounting alone does not necessarily lead to immediate operational improvements, especially in industries where low-carbon technologies are still evolving [7,8].

In this context, digital transformation has emerged as a critical enabler for strengthening carbon accounting systems and improving financial decision-making. The integration of technologies such as artificial intelligence, big data analytics, blockchain, and the Internet of Things (IoT) improves the accuracy, timeliness, and reliability of emissions data. According to Vial (2019), digital transformation fundamentally reshapes organizational value creation through data-driven decision processes [9]. Similarly, Schallmo and Williams (2017) emphasize that digital transformation enhances performance management systems by enabling real-time integration of operational and sustainability data [10]. These technologies allow firms to embed carbon metrics directly into financial systems, improving forecasting, scenario analysis, and investment evaluation.

Moreover, global uncertainty has become a defining characteristic of the operating environment for high-emission industries. Geopolitical tensions, supply chain disruptions, energy price volatility, and evolving climate regulations increase financial risk exposure and reduce predictability in investment outcomes. Baker et al. (2016) highlight that uncertainty significantly affects investment behavior and corporate decision-making [11]. In high-emission industries, this uncertainty is further amplified by climate transition risks and regulatory shifts, requiring firms to adopt more adaptive and data-driven decision frameworks. Carbon accounting, when integrated with digital tools, enhances firms' ability to conduct scenario planning and assess financial exposure under different policy and market conditions.

Energy efficiency also plays a crucial role in linking sustainability objectives with financial performance. According to the International Energy Agency (IEA), energy efficiency is one of the most cost-effective pathways for reducing emissions while improving economic productivity [12]. Furthermore, Lovins (2018) argues that efficiency investments often generate immediate financial returns through cost reduction and productivity gains, making them a strategic lever for both environmental and financial performance improvement [13]. In high-emission industries, energy efficiency initiatives reduce opera-

tional costs and carbon intensity simultaneously, thereby strengthening overall financial decision-making quality.

Accordingly, this study examines the role of carbon accounting, digital transformation, global uncertainty, and energy efficiency in improving financial decision-making and supporting sustainability in high-emission industries. The study focuses on manufacturing firms within photovoltaic-related sectors, with particular attention to Palestinian industrial companies operating under economic volatility and resource constraints. By integrating these four dimensions, the research aims to provide a more comprehensive understanding of how sustainability-oriented accounting practices and digital capabilities can jointly enhance financial outcomes and environmental performance.

2. Literature Review & Hypotheses Development

2.1. Literature Review

2.1.1. The Concept of Carbon Accounting

Carbon accounting has emerged as a central concept in contemporary sustainability and climate governance, driven by increasing global pressures on organizations to measure, manage, and disclose greenhouse gas emissions. Rather than being a uniform concept, the literature reveals that carbon accounting is interpreted from multiple but partially overlapping perspectives, reflecting differences in emphasis between measurement systems, managerial applications, and strategic sustainability objectives.

Ref. [6] conceptualizes carbon accounting primarily as a measurement and reporting process focused on quantifying greenhouse gas emissions and integrating environmental data into traditional accounting systems. This definition places strong emphasis on technical measurement and reporting accuracy.

In contrast, ref. [14] extends the concept beyond measurement, framing carbon accounting as an integrated managerial system that supports decision-making and emissions management within organizations. This view shifts the focus from mere reporting to active managerial use of carbon data.

Similarly, ref. [15] highlights carbon accounting as a strategic accounting approach that captures the carbon costs associated with organizational activities, thereby linking emissions information to sustainability-oriented accounting practices. Compared to earlier definitions, this perspective places greater emphasis on cost allocation and strategic integration.

Ref. [16], however, broadens the discussion by positioning carbon accounting as a mechanism for achieving sustainability outcomes through improved resource efficiency and reduced emissions, thereby emphasizing performance and outcomes rather than processes.

Despite these contributions, a critical review of the literature reveals that most definitions remain fragmented and partially reductionist. Some studies focus narrowly on emissions measurement [6], while others emphasize managerial decision support [14] or sustainability outcomes [16].

This fragmentation indicates a lack of a unified conceptual framework that integrates the technical, managerial, and strategic dimensions of carbon accounting within a single coherent model.

Accordingly, carbon accounting can be synthesized as an integrated accounting system that not only measures and reports carbon emissions but also supports managerial decision-making and contributes to organizational sustainability performance. However, the existing literature still lacks sufficient theoretical integration that connects carbon accounting with broader organizational frameworks such as strategic management, dynamic capabilities, or institutional pressures, which limits its explanatory power in understanding how organizations transform carbon information into strategic action.

2.1.2. Carbon Accounting Practices in High-Emission Industries

Carbon accounting has become an increasingly important practice in high-emission industries due to growing regulatory requirements, climate-related risks, and the rising demand for corporate environmental transparency. Carbon-intensive sectors, including cement, chemicals, and petroleum refining, are among the major contributors to greenhouse gas emissions because of their reliance on energy-intensive production processes and fossil fuel-based inputs. Consequently, effective carbon accounting systems are considered essential for accurately measuring emissions, improving environmental reporting, and supporting strategic decision-making related to sustainability and operational efficiency.

Recent literature emphasizes the importance of reliable carbon accounting systems in addressing the complexity and variability of industrial emission sources. Ref. [17] highlights that high-emission industries require accurate carbon measurement mechanisms to ensure effective emissions monitoring. However, their study primarily focuses on the technical accuracy of emissions tracking rather than examining how carbon information is incorporated into strategic and managerial decision-making processes. Similarly, research in the petroleum refining sector emphasizes the identification of emission hotspots across production chains to enhance environmental management practices. Nevertheless, such approaches remain largely descriptive and provide limited insight into the organizational and institutional factors that influence firms' ability to utilize carbon-related information.

At the methodological level, the Greenhouse Gas Protocol provides a widely recognized framework for emissions classification through Scopes 1, 2, and 3. However, the practical implementation of these standards remains inconsistent across industries due to differences in technological capabilities, data availability, and reporting practices. This gap between standardized frameworks and organizational implementation highlights ongoing challenges related to measurement consistency, comparability, and verification of carbon information.

Recent empirical studies provide evidence of the potential benefits of carbon accounting adoption. Ref. [18] demonstrates that carbon accounting can enhance regulatory compliance and environmental transparency, while ref. [19] associates carbon accounting practices with improved corporate reputation and market value. However, these studies largely emphasize the positive outcomes of adoption and provide limited attention to contextual challenges, including data limitations, measurement uncertainty, technological constraints, and institutional differences across countries.

Conversely, critical perspectives highlight several barriers affecting the effective implementation of carbon accounting systems. Ref. [17] identifies difficulties related to data collection and emission measurement within complex industrial processes, whereas ref. [20] emphasizes inconsistencies in carbon accounting standards across jurisdictions that limit comparability and external verification. Furthermore, ref. [21] highlights the challenges associated with Scope 3 emissions, which depend heavily on external supply-chain data that may be incomplete or unreliable. In addition, ref. [22] points to the substantial financial and technological investments required to implement advanced carbon accounting systems, particularly in heavy industries.

Overall, the literature indicates that while carbon accounting provides significant benefits in terms of compliance, transparency, reputation, and operational improvement, its effective implementation remains constrained by technological, organizational, and institutional challenges. Existing research has largely focused on the reporting and environmental benefits of carbon accounting, while fewer studies have examined how these systems can be integrated with organizational capabilities, governance mechanisms, and strategic decision-making processes. Therefore, a significant research gap remains regarding how carbon accounting can be effectively operationalized in high-emission industries

under conditions of technological limitations, data uncertainty, and regulatory variation. Addressing this gap requires an integrated perspective that moves beyond descriptive disclosure practices toward understanding the role of carbon accounting in enhancing managerial decision-making and organizational sustainability performance.

2.1.3. Financial Decisions in Industrial Companies

Financial decisions in industrial companies are widely recognized as a core mechanism for achieving economic sustainability and enhancing competitive advantage.

The literature generally agrees that such decisions involve the allocation of financial resources in ways that balance investment growth, financing structure, risk exposure, and cost efficiency [23].

However, despite this conceptual agreement, existing studies tend to differ in the extent to which they integrate these decision types into a unified strategic framework, with most research addressing them in isolation rather than as interdependent components of financial strategy. Investment decisions are frequently highlighted as the most analytically developed area within financial decision-making research.

Ref. [24] emphasizes the use of capital budgeting tools such as Net Present Value (NPV) and Internal Rate of Return (IRR) to evaluate project feasibility and profitability. While this approach provides strong quantitative foundations, it remains largely focused on deterministic financial evaluation and gives limited consideration to external uncertainties such as market volatility, regulatory changes, or sustainability-related risks, which are increasingly relevant in industrial contexts. Financing decisions, on the other hand, are commonly discussed in terms of optimizing capital structure through a balance of debt, equity, and internal financing.

Ref. [23] argues that financing structure significantly affects liquidity and financial reporting outcomes. However, much of the existing literature adopts a normative perspective on “optimal capital structure,” while paying less attention to how real-world constraints—such as credit accessibility, institutional environments, or economic instability—shape actual financing behavior in industrial firms.

Risk management decisions are presented in the literature as essential for ensuring financial stability by identifying and mitigating market, interest rate, and operational risks [25]. Nevertheless, most studies conceptualize risk management as a technical or procedural function, without sufficiently exploring its integration into strategic financial planning or its interaction with investment and financing decisions. This creates a fragmented understanding of risk as a separate function rather than a cross-cutting dimension of financial decision-making.

Cost-related decisions are primarily addressed through cost accounting and management accounting systems, which provide data for monitoring production efficiency and controlling operational expenses [23].

While these systems are widely acknowledged as decision-support tools, existing studies often assume the availability of accurate and timely cost data, without critically addressing issues such as data quality, system integration, or managerial interpretation biases, which may limit their practical effectiveness. Recent studies emphasize the role of accounting information systems in enhancing financial decision quality.

Ref. [26] argues that reliable accounting information reduces uncertainty and improves the quality of investment and financing decisions, while ref. [27] highlights its role in supporting risk assessment and capital allocation efficiency. However, these studies generally adopt an efficiency-oriented perspective, assuming that better information automatically leads to better decisions, without critically examining how cognitive limitations, organizational politics, or institutional pressures may distort decision use in practice.

Overall, the literature reveals a strong tendency to treat financial decisions as technically rational processes driven by quantitative models and accounting information systems. However, this perspective underestimates the interdependence between investment, financing, risk, and cost decisions, as well as the contextual factors that influence managerial decision-making in industrial environments. Consequently, a key gap emerges in understanding how financial decision-making systems operate as integrated strategic mechanisms under conditions of uncertainty, resource constraints, and environmental pressures.

2.1.4. The Role of Carbon Accounting in Financial Decision-Making

The relationship between carbon accounting information and financial decision-making has received increasing attention in recent accounting and finance literature, particularly in high-emission industries where environmental impacts are closely connected to financial risks and opportunities. Although previous studies generally suggest that carbon accounting improves decision quality by providing relevant environmental information, the literature remains inconclusive regarding the organizational mechanisms and contextual conditions through which carbon information creates strategic financial value.

Regarding investment decisions, previous research indicates that carbon disclosure enhances transparency by providing investors with additional non-financial information that supports more informed project evaluation, particularly for sustainability-oriented investments [28]. However, this perspective often assumes that investors consistently interpret and incorporate carbon information into their decisions, while paying limited attention to differences in investor expertise, market efficiency, and regulatory environments that may influence the actual usefulness of such information.

In financing decisions, recent studies provide evidence that carbon disclosure can reduce financing constraints by signaling lower environmental risks to lenders and capital providers. Ref. [29] demonstrates that carbon disclosure is associated with reduced debt financing costs, suggesting that environmental transparency can improve firms' access to capital. Similarly, ref. [30], using evidence from listed Egyptian companies, finds that higher levels of carbon disclosure were linked to lower financing costs. Nevertheless, these findings remain largely associative and do not fully establish causality, as financially stronger firms may possess greater resources to implement carbon disclosure practices rather than disclosure itself being the primary driver of improved financing conditions.

Beyond disclosure practices, recent literature emphasizes the importance of integrating carbon-related costs and emissions information into accounting systems to support financial planning and operational efficiency. Ref. [31] highlights that environmental and carbon costing systems enable organizations to incorporate environmental costs into managerial accounting processes. However, empirical evidence regarding the practical implementation of such systems remains limited, particularly concerning challenges related to data availability, measurement complexity, system integration, and organizational readiness.

From a stakeholder and market perspective, carbon disclosure has also been associated with enhanced corporate reputation, improved stakeholder relationships, and greater market value. Studies suggest that environmentally conscious investors are increasingly likely to support firms demonstrating higher levels of carbon transparency, potentially reducing financing constraints and encouraging environmental innovation [32,33]. However, this optimistic perspective may overlook situations where carbon disclosure is perceived as a compliance burden, an additional operational cost, or even a competitive disadvantage, particularly in industries facing significant regulatory and technological pressures.

Despite these potential benefits, recent research has increasingly highlighted important limitations related to the credibility and reliability of carbon accounting information. Carbon accounting—particularly the measurement of Scope 3 emissions—is subject to

considerable uncertainty resulting from differences in calculation methodologies, organizational reporting boundaries, estimation assumptions, and limited availability of reliable supply-chain data. Ref. [34] emphasizes that these methodological differences reduce the comparability and reliability of reported emissions information, thereby affecting its usefulness for managerial and investment decisions.

At the same time, the growing adoption of carbon disclosure has intensified concerns regarding symbolic environmental reporting and greenwashing. Rather than reflecting genuine environmental improvement, some organizations may selectively disclose favorable environmental information or strategically emphasize sustainability initiatives to enhance legitimacy and stakeholder confidence without achieving proportional improvements in actual environmental performance. Consequently, the value of carbon accounting depends not only on the availability of environmental information but also on the credibility of disclosure, robust verification mechanisms, transparent reporting practices, sound data governance, and managerial capability to interpret environmental information effectively. These challenges indicate that carbon accounting should be viewed as a governance and decision-support capability rather than merely a technical reporting mechanism.

Overall, the existing literature provides valuable evidence regarding the positive role of carbon accounting in improving investment decisions, reducing financing costs, and enhancing stakeholder confidence. Nevertheless, current research remains limited in explaining how carbon information is transformed into strategic financial value under different organizational and environmental conditions. In particular, insufficient attention has been given to the complementary roles of organizational capabilities, digital competence, and environmental uncertainty in determining the effectiveness of carbon accounting systems, while recent evidence also calls for greater consideration of measurement uncertainty and greenwashing risks when evaluating the quality and usefulness of sustainability information.

Accordingly, this study addresses these gaps by conceptualizing carbon accounting as a dynamic organizational sensing capability within the Dynamic Capabilities Theory framework. Rather than treating carbon accounting solely as a disclosure mechanism, this study views it as a strategic capability that generates environmental intelligence to support financial decision-making. Furthermore, the study recognizes that the strategic value of carbon accounting depends on the quality and credibility of environmental information, the organization's capability to integrate such information through digital transformation, and its ability to respond effectively to environmental uncertainty in high-emission industries.

2.1.5. Digital Transformation and Its Role in Financial Decision-Making and Sustainability

Recent research increasingly emphasizes the role of digital transformation capabilities in enhancing sustainability performance through improved data integration, operational transparency, resource optimization, and decision-making efficiency. Digital transformation extends beyond the adoption of advanced technologies, such as artificial intelligence (AI), the Internet of Things (IoT), cloud computing, and blockchain, representing a broader organizational transformation that reshapes structures, business processes, and managerial decision-making systems. Ref. [9] conceptualizes digital transformation as a process through which organizations leverage digital technologies to reconfigure capabilities and create new forms of value. Similarly, ref. [35] argues that the strategic integration of digital technologies with organizational processes and capabilities is essential for achieving sustainable competitive advantage.

Within sustainability-oriented operations, digital transformation has become an important enabler of environmental monitoring, resource efficiency, and sustainability information management. Digital technologies facilitate real-time data collection, improve

traceability, and support more accurate measurement of environmental impacts. For example, Industry 4.0 technologies enable organizations to optimize resource utilization and enhance environmental performance through improved operational control and data-driven decision-making [36]. Furthermore, digital systems strengthen carbon accounting practices by improving emissions measurement, reporting accuracy, and information transparency across organizational and supply chain activities.

However, the relationship between digital transformation and sustainability outcomes is neither automatic nor universally positive. Although previous studies highlight the potential benefits of digital technologies, they often adopt a technology-centric perspective that implicitly assumes digital investments will generate superior sustainability and financial outcomes. Existing evidence suggests that the effectiveness of digital transformation depends on contextual conditions, including technological readiness, data governance, organizational capabilities, and managerial ability to interpret and utilize digital information effectively.

From a financial decision-making perspective, digital transformation is frequently associated with enhanced managerial decision quality through the integration of financial and non-financial information within enterprise platforms and digital information systems. Ref. [37] argues that digital technologies improve productivity and organizational performance only when complemented by appropriate organizational capabilities and intangible resources. Consequently, greater data availability alone does not guarantee better decisions; rather, the value of digital information depends on organizational learning, analytical capabilities, and effective managerial interpretation.

Recent research in strategic management and operations management further emphasizes that the sustainability benefits of digital transformation depend on the development of digital competence rather than technology adoption alone. Digital competence refers to an organization's ability to integrate digital technologies, data analytics, organizational knowledge, employee digital skills, and managerial capabilities to create strategic value. Unlike technology-centric perspectives, which assume that digital investments directly improve organizational outcomes, the digital competence perspective highlights the complementary role of organizational capabilities, strategic alignment, data governance, and analytical capacity in converting technological resources into operational improvements, innovation, and sustainable performance.

Evidence from leading management and operations journals supports this capability-based perspective. For example, research published in the *Journal of Operations Management* demonstrates that analytics capabilities strengthen firms' ability to transform large volumes of digital data into operational and strategic improvements, indicating that the value of digital technologies depends on organizational capabilities rather than technology adoption itself [38]. Likewise, recent sustainability management research emphasizes that digital technologies contribute to sustainability performance only when organizations develop the managerial and organizational capabilities required to govern, interpret, and deploy digital resources effectively [39]. These findings are consistent with Dynamic Capabilities Theory, which suggests that competitive advantage arises from the organization's ability to integrate, build, and reconfigure internal and external resources in response to rapidly changing environments.

At the same time, recent sustainability literature cautions that digital technologies may also amplify sustainability-related risks if governance mechanisms are weak. The increasing availability of environmental data does not necessarily improve reporting quality, as measurement uncertainties, inconsistent emissions estimation methods, and selective disclosure practices may reduce the credibility of carbon accounting information and increase the risk of greenwashing. Consequently, digital technologies should be viewed as

enablers of sustainability performance only when supported by robust governance systems, transparent reporting practices, and reliable environmental measurement processes.

Despite these important developments, the literature remains fragmented regarding how digital transformation capabilities interact with sustainability information systems, particularly carbon accounting, to influence financial decision-making quality in high-emission industries. Existing studies have primarily examined digital transformation either as a technological enabler of sustainability performance or as a driver of operational efficiency, while giving limited attention to the organizational mechanisms through which digital capabilities transform sustainability-related information into strategic financial value. Furthermore, limited research has explicitly incorporated digital competence, reporting credibility, measurement uncertainty, and greenwashing risks within a unified theoretical framework.

Accordingly, this study extends the digital transformation perspective by conceptualizing digital competence as the organizational capability that enables firms to integrate digital technologies, analytics, managerial knowledge, and sustainability information, while conceptualizing digital transformation as a seizing capability within the Dynamic Capabilities Theory framework. In this capability architecture, carbon accounting provides environmental information that is interpreted and exploited through digital competence, enabling organizations to convert sustainability-related information into higher-quality financial decisions and improved sustainability performance. This perspective contributes to the literature by explaining not only how digital technologies support organizational performance but also why their effectiveness depends on complementary organizational capabilities, information credibility, and the governance of sustainability-related data under conditions of environmental uncertainty.

2.1.6. Global Uncertainty and Its Impact on Industrial Financial Decisions

Global uncertainty has increasingly become a defining feature of the contemporary economic environment, influencing corporate financial behavior, particularly in high-emission and capital-intensive industries. It is broadly associated with unpredictability arising from geopolitical tensions, economic volatility, supply chain disruptions, energy price fluctuations, and evolving climate policies. Early influential work by [40] suggests that uncertainty shocks generally lead to delayed investment and lower economic growth due to increased risk aversion and managerial caution, while ref. [11] similarly finds that economic policy uncertainty negatively affects corporate investment and financing decisions. Although these studies provide strong macroeconomic evidence, they largely assume homogeneous firm responses and give limited attention to heterogeneity across industries, governance structures, and strategic capabilities.

In this regard, recent research [11,41] Policy Uncertainty and Corporate Investment; ref. [42] Climate Change and Firm-Level Investment; ref. [43] indicates that the effects of uncertainty in industrial and energy-intensive sectors are highly variable and context-dependent, particularly under climate-related transition risks. Firms operating in high-emission industries face heightened exposure to regulatory uncertainty stemming from anticipated carbon pricing mechanisms, stricter environmental policies, and technological transitions associated with the shift toward a low-carbon economy. From a financial stability perspective, these climate-related risks are increasingly recognized as systemic in nature, as they simultaneously affect asset valuation, investment timing, and profitability expectations across interconnected markets. Empirical evidence further shows that political and climate uncertainty can distort institutional investment behavior and intensify risk aversion, especially in capital-intensive sectors where long-term investment decisions are highly sensitive to regulatory expectations. Similarly, firm-level studies suggest that climate policy

uncertainty is associated with reduced investment activity and accelerated restructuring of corporate risk management practices within emissions-intensive industries. Collectively, this evidence demonstrates that uncertainty effects are neither uniform nor linear but rather shaped by sectoral characteristics, regulatory exposure, and firms' adaptive capacities.

Within this context, carbon accounting has increasingly been positioned as a mechanism for reducing informational uncertainty and strengthening risk assessment capabilities. By providing structured and standardized emissions data, it enables firms to better anticipate regulatory costs, environmental liabilities, and transition risks. However, the literature often adopts an overly optimistic view of its effectiveness, implicitly assuming that improved carbon information directly translates into superior risk management outcomes, while paying insufficient attention to constraints such as measurement uncertainty, inconsistent reporting standards, and variations in managerial interpretation of environmental data. In parallel, digital transformation technologies are widely argued to enhance the effectiveness of carbon accounting by enabling advanced analytics, scenario modeling, and real-time monitoring of emissions through technologies such as artificial intelligence, the Internet of Things, cloud computing, and blockchain. Nevertheless, this integration remains largely conceptual, with limited empirical evidence on whether such technologically enabled systems actually improve financial resilience in practice, particularly in firms with heterogeneous digital capabilities and resource constraints.

Overall, while the literature broadly recognizes global uncertainty as a driver of more cautious and risk-averse financial behavior, it tends to rely on linear and deterministic assumptions regarding its effects and mitigation mechanisms. This perspective underestimates the role of organizational capabilities, institutional environments, and uneven technological adoption in shaping firm responses. Accordingly, a key research gap emerges in understanding how global uncertainty interacts with carbon accounting and digital transformation systems to jointly influence financial decision-making quality in high-emission industries under varying institutional, technological, and regulatory conditions.

2.1.7. Energy Efficiency and Its Contribution to Sustainability and Financial Performance

Energy efficiency is widely recognized in the literature as a key strategy for simultaneously achieving environmental sustainability and improving corporate financial performance. It is generally defined as a reduction in energy input required to produce a given level of output without compromising production quality. However, while there is broad agreement on its importance, the literature differs in the extent to which it conceptualizes energy efficiency as either a technological solution, an economic optimization tool, or a structural transition mechanism.

At the firm level, energy efficiency has been widely recognized in the academic literature as a key driver of cost reduction, productivity improvement, and competitive advantage. Empirical evidence from firm-level studies indicates that energy-efficient firms tend to achieve higher productivity and stronger financial performance compared to less efficient counterparts [44,45].

In addition, recent firm-level empirical studies provide robust evidence that improvements in energy efficiency are associated with significant reductions in production costs and enhanced operational performance, particularly in energy-intensive manufacturing industries. For instance, ref. [44] finds that energy efficiency is positively linked to firm-level productivity across a large international sample of firms. Similarly, ref. [46] demonstrates that improvements in energy performance are associated with lower operational costs and higher production efficiency in manufacturing firms over time. Moreover, ref. [47] shows that energy efficiency interventions in industrial firms lead to measurable reductions in

energy expenditure and improvements in operational outcomes, although the magnitude of these effects depends on management practices and organizational readiness.

However, these benefits are not automatic, as empirical studies [43,46–49] show that the effectiveness of energy efficiency improvements depends on firms' technological readiness, investment capacity, and organizational capabilities. In particular, heterogeneity in firm characteristics significantly influences the extent to which energy efficiency translates into operational and environmental gains, especially in energy-intensive industries. Collectively, these studies indicate that energy efficiency improvements contribute to broader sustainability and emissions reduction objectives but only under specific organizational and contextual conditions.

Beyond operational performance, the literature further extends the discussion to the financial implications of energy efficiency. From a corporate finance perspective, energy efficiency is commonly associated with reduced operational costs, improved profit margins, and lower exposure to energy price volatility. Ref. [45] finds that energy-efficient firms tend to outperform less efficient firms in terms of financial performance and environmental risk exposure.

However, this strand of literature largely assumes a direct and linear relationship between efficiency improvements and financial gains while giving less attention to the high upfront investment costs, technological adoption barriers, and payback period uncertainties that may delay or limit financial benefits, especially in capital-intensive industrial sectors.

In addition, the literature suggests that energy efficiency enhances the quality of carbon accounting systems by reducing emission intensity and improving the reliability of sustainability disclosures. However, this relationship is often treated as automatic rather than conditional. In practice, the extent to which efficiency improvements translate into more accurate carbon reporting depends on the sophistication of accounting systems, data integration capabilities, and the consistency of measurement standards across firms and industries.

Furthermore, although energy efficiency is frequently linked to improved corporate reputation and regulatory compliance, much of the existing research adopts a predominantly positive framing and underexplores potential trade-offs. For instance, efficiency improvements may not necessarily lead to proportional emission reductions due to rebound effects, where cost savings are partially offset by increased production or consumption levels. This issue remains underexplored in the accounting and financial literature.

Overall, while the literature strongly supports energy efficiency as a mechanism linking environmental sustainability with improved financial outcomes, this relationship is often presented in a simplified and deterministic manner. Less attention is given to contextual factors such as investment constraints, technological readiness, institutional pressures, and behavioral responses within organizations.

Accordingly, a key research gap remains in understanding how energy efficiency interacts with carbon accounting systems and financial decision-making processes in high-emission industries, particularly under conditions of uncertainty, resource limitations, and heterogeneous technological capabilities.

2.1.8. Integrated Framework: Linking Carbon Accounting, Digital Transformation, Global Uncertainty, and Energy Efficiency

The increasing complexity of high-emission industries has led to growing calls in the literature for a more integrated understanding of how sustainability-related practices influence financial decision-making. Although carbon accounting is widely recognized as a foundational mechanism for capturing emissions and environmental costs, the literature suggests that its effectiveness is not inherent but contingent upon its integration with

broader technological, organizational, and contextual factors such as digital transformation, global uncertainty, and energy efficiency [35].

However, existing studies often treat these elements as complementary rather than interdependent, resulting in fragmented explanations of how sustainability information is actually translated into financial decisions. Digital transformation is frequently positioned as the main enabling infrastructure for this integration. The adoption of technologies such as artificial intelligence, the Internet of Things (IoT), blockchain, and big data analytics is shown to enhance the accuracy, timeliness, and traceability of carbon data. It also facilitates the embedding of environmental information into financial and managerial systems, thereby improving investment appraisal, cost control, and risk assessment processes.

Ref. [37] argues that such technologies improve decision quality through enhanced data utilization. However, this perspective tends to be overly technology-centric, implicitly assuming that improved data availability automatically leads to improved decision-making, while underexploring organizational constraints such as managerial interpretation, system interoperability, and digital capability gaps. Similarly, global uncertainty is widely recognized as a critical contextual factor that shapes corporate financial behavior. Economic volatility, geopolitical tensions, energy price fluctuations, and regulatory shifts increase the complexity of financial planning and investment decisions [40,41].

Recent studies further emphasize the importance of broader institutional and innovation-related conditions in shaping sustainability transitions and the effectiveness of environmental practices. Ref. [46] demonstrates that political stabilization plays a significant role in facilitating clean energy transitions by creating a more supportive environment for renewable energy adoption, whereas political destabilization can hinder such transitions by increasing uncertainty and constraining long-term sustainability investments. This evidence highlights that sustainability-oriented financial decisions are not determined solely by internal organizational capabilities but are also influenced by external institutional conditions that shape firms' ability to respond to environmental challenges.

Similarly, ref. [47] highlights the critical role of technological innovation in strengthening the impact of environmental policies, renewable energy adoption, and sustainable development strategies. The findings indicate that innovation contributes to reducing environmental pressures and supports low-carbon transformation by enhancing the effectiveness of renewable energy and sustainability initiatives. These insights reinforce the argument that technological capabilities and innovation are essential mechanisms through which organizations can convert environmental knowledge into improved operational and financial outcomes. Therefore, the integration of innovation capacity and external institutional conditions provides a more comprehensive understanding of how sustainability practices influence financial decision-making, particularly in high-emission industries facing increasing environmental and regulatory pressures.

While the literature generally associates uncertainty with reduced investment and increased risk aversion, this relationship is not always linear or uniform across firms and industries. In high-emission sectors, uncertainty is further intensified by climate transition risks, yet empirical evidence remains limited on how firms actually incorporate carbon accounting information into decision-making under such volatile conditions. As a result, carbon accounting is often assumed to function as a stabilizing tool, although its effectiveness under high uncertainty remains insufficiently examined. Energy efficiency is commonly presented as a direct operational mechanism that links environmental performance with financial outcomes.

Ref. [45] highlights its role in reducing operational costs and improving financial performance. However, much of the literature assumes a straightforward conversion of efficiency gains into financial benefits, overlooking important constraints such as high

upfront investment costs, payback uncertainty, and the rebound effect, which may reduce the expected environmental and financial gains. This indicates that the relationship between energy efficiency and financial performance is more conditional than typically presented.

Overall, while the literature conceptually supports the integration of carbon accounting, digital transformation, global uncertainty, and energy efficiency, it largely remains fragmented and overly optimistic in its assumptions. Most studies focus on the individual benefits of each factor rather than critically examining their interdependencies, limitations, and potential trade-offs in real industrial contexts. Consequently, a key gap emerges in understanding how these elements jointly operate as a dynamic system influencing the quality of financial decision-making in high-emission industries, particularly under conditions of technological disparity, regulatory pressure, and environmental uncertainty.

Accordingly, these elements can be conceptualized as an interdependent strategic system in which carbon accounting generates environmental intelligence (sensing), digital transformation enables data-driven interpretation and decision activation (seizing), and energy efficiency reflects operational reconfiguration outcomes, all of which are continuously reshaped under conditions of global uncertainty, which acts as an external pressure intensifying the need for adaptive financial decision-making.

Although previous studies have examined carbon accounting, digital transformation, global uncertainty, and energy efficiency from relatively separate perspectives, this study argues that these constructs represent interconnected components of a dynamic organizational capability system rather than isolated factors. Drawing on Dynamic Capabilities Theory, the relationship among these constructs can be understood through the firm's ability to sense environmental changes, seize emerging opportunities, and reconfigure resources to maintain financial decision-making effectiveness under uncertainty.

Within this framework, carbon accounting represents a sensing capability that enables organizations to identify carbon-related risks, environmental costs, and sustainability-related opportunities through the systematic generation of emissions information. However, the value of carbon accounting does not arise solely from measurement and disclosure; rather, it depends on the organization's ability to transform environmental information into actionable knowledge. Therefore, digital transformation functions as an enabling capability that facilitates the integration, analysis, and utilization of carbon-related data through advanced digital technologies, thereby strengthening managerial decision-making processes.

Furthermore, energy efficiency reflects the outcome of organizational reconfiguration, where firms translate environmental knowledge and digital capabilities into operational improvements, resource optimization, and cost advantages. In contrast, global uncertainty represents the external environmental pressure that increases the need for dynamic capabilities by challenging firms to continuously adapt their financial and operational decisions. Accordingly, uncertainty does not operate merely as an independent risk factor but as a contextual condition that determines the extent to which firms must develop and deploy adaptive capabilities.

Therefore, the proposed framework conceptualizes carbon accounting, digital transformation, and energy efficiency as mutually reinforcing dimensions of dynamic capabilities, while global uncertainty acts as an external condition shaping their effectiveness in improving financial decision-making quality. This integrated perspective overcomes the fragmented treatment of these constructs in previous research and provides a theoretically grounded explanation of how sustainability-oriented information and technological capabilities are transformed into strategic financial outcomes.

2.1.9. Research Gap

Despite the expanding literature on carbon accounting, digital transformation, global uncertainty, and energy efficiency, existing research remains fragmented and lacks an integrated explanation of how these dimensions jointly shape financial decision-making in high-emission industries.

First, although studies on carbon accounting [6,14–16] have significantly advanced knowledge regarding emissions measurement, disclosure practices, and sustainability reporting, they remain largely focused on technical and reporting aspects, with limited attention to how carbon-related information is transformed into strategic financial decisions. Similarly, studies on digital transformation [36,37] primarily emphasize technological adoption and operational efficiency, often assuming that digitalization automatically improves organizational performance without sufficiently explaining the organizational capabilities through which digital technologies generate strategic value. In particular, limited attention has been given to the role of digital competence as an organizational capability that enables firms to integrate digital technologies, managerial expertise, and sustainability information to improve long-term financial and sustainability outcomes.

Second, prior research on global uncertainty [44,45] consistently shows that economic, geopolitical, and climate-related uncertainty adversely affects investment and financing decisions. However, these studies mainly adopt a risk-exposure perspective and provide limited theoretical explanation of why some organizations are more capable than others of maintaining decision quality under uncertain conditions. Consequently, uncertainty has rarely been examined as a contextual condition that shapes the effectiveness of organizational capabilities.

Third, although previous studies [44,49] demonstrate that energy efficiency contributes to productivity improvement and financial performance, they generally assume a direct and linear relationship between operational efficiency and organizational outcomes. Relatively little attention has been devoted to understanding how firms develop the organizational capabilities required to transform efficiency improvements into sustainable financial advantages, particularly under rapidly changing environmental and technological conditions.

Furthermore, existing research provides insufficient discussion of the limitations associated with carbon accounting. While most studies emphasize its contribution to transparency and sustainability, relatively few critically examine the risks of greenwashing, symbolic environmental disclosure, and the substantial measurement uncertainties associated with carbon accounting, particularly regarding Scope 3 emissions, inconsistent reporting methodologies, and data comparability. These limitations raise important questions regarding the reliability of carbon information as a basis for strategic financial decision-making.

From a theoretical perspective, the literature also reveals important limitations. Although Dynamic Capabilities Theory has been widely applied to explain organizational adaptation and sustainability transformation, limited attention has been given to how carbon accounting, digital competence, and energy efficiency collectively operate as complementary dynamic capabilities that enhance financial decision-making quality. Moreover, existing studies generally assume linear relationships between sustainability initiatives and organizational performance, while giving insufficient consideration to the possibility that implementation costs, organizational learning, and external uncertainty may influence the timing and magnitude of these relationships.

Accordingly, the principal research gap is not merely the limited simultaneous examination of carbon accounting, digital transformation, global uncertainty, and energy efficiency but the absence of a theoretically grounded explanation of how these constructs

interact as an integrated system of dynamic organizational capabilities that enhances financial decision-making quality under conditions of environmental uncertainty.

Therefore, this study extends Dynamic Capabilities Theory by proposing an integrated sustainability-oriented capability framework in which carbon accounting represents an environmental sensing capability, digital competence and digital transformation represent capabilities for knowledge integration and opportunity exploitation, and energy efficiency reflects organizational resource reconfiguration toward improved financial and sustainability outcomes. In addition, global uncertainty is conceptualized as a contextual boundary condition that shapes the deployment and effectiveness of these capabilities in high-emission industries.

Thus, the contribution of this study extends beyond examining the direct effects of sustainability-related practices. Instead, it provides a capability-based explanation of how sustainability information, digital competence, and organizational capabilities interact to improve financial decision-making quality while acknowledging the credibility challenges associated with carbon accounting and the influence of environmental uncertainty.

2.2. Theoretical Foundation: Dynamic Capabilities Perspective

To overcome the fragmented conceptualization identified in the previous literature, this study is grounded in Dynamic Capabilities Theory (DCT), which explains how firms integrate, build, and reconfigure internal and external competencies to respond to rapidly changing environments and sustain performance advantages under uncertainty [47,48]. Unlike static perspectives such as the Resource-Based View, DCT emphasizes continuous adaptation and organizational renewal rather than the possession of resources alone.

Recent developments in the literature extend DCT into digitally intensive and sustainability-driven contexts, where competitive advantage is increasingly determined by a firm's ability to orchestrate data, technology, and knowledge into adaptive decision systems refs. [9,50–53]. In such environments, dynamic capabilities are not limited to strategic renewal but include digital sensing, analytics integration, and sustainability-oriented transformation capabilities.

Within this theoretical lens, carbon accounting is conceptualized as a sensing capability, enabling firms to identify, measure, and interpret emissions-related risks, regulatory exposure, and operational inefficiencies. Digital transformation represents a seizing capability through which organizations convert carbon-related data into actionable insights using advanced technologies such as artificial intelligence, the Internet of Things (IoT), cloud computing, and blockchain. Energy efficiency reflects a reconfiguring capability, as firms restructure operational processes, technologies, and resource utilization patterns to improve sustainability and financial outcomes.

Global uncertainty functions as a contextual environmental condition that amplifies the importance of dynamic capabilities by increasing volatility, regulatory unpredictability, and investment risk [11,40]. In high-emission industries, these pressures are further intensified by climate transition risks, requiring firms to continuously adjust their financial and operational strategies.

Empirical studies support this integrated view. Ref. [54] demonstrates that digital transformation constitutes a dynamic capability requiring continuous organizational reconfiguration rather than being a purely technological upgrade. Similarly, ref. [55] finds that data analytics capabilities significantly enhance strategic flexibility and decision-making quality under uncertainty. In sustainability contexts, ref. [56] shows that dynamic capabilities strengthen environmental innovation and green performance.

Unlike prior studies that primarily examine dynamic capabilities as a general mechanism for achieving sustainability performance, this study extends the theory by positioning

sustainability-oriented capabilities as an integrated decision-enabling architecture. Specifically, the study argues that carbon accounting provides the sensing foundation through environmental intelligence, digital transformation enables the seizing and utilization of this intelligence, and energy efficiency facilitates resource reconfiguration toward improved financial outcomes. Furthermore, by incorporating global uncertainty as a contextual condition, this study advances Dynamic Capabilities Theory by explaining how external volatility shapes the deployment and effectiveness of sustainability-related capabilities in high-emission industries.

Accordingly, Dynamic Capabilities Theory provides a comprehensive explanatory framework for this study, as it captures the interdependent and evolving relationships among carbon accounting, digital transformation, global uncertainty, and energy efficiency in shaping financial decision-making quality in high-emission industries.

2.3. Hypotheses Development

2.3.1. Carbon Accounting, Financial Decision-Making, and Sustainability

Recent literature indicates that carbon accounting has become an essential tool for enhancing the transparency of environmental disclosure and improving the quality of accounting information used in financial decision-making. Multiple studies have shown that measuring and disclosing carbon emissions enhances the informational value of financial reports and influences market assessments of corporate performance [5,19]. Despite mixed and sometimes contradictory empirical evidence—some studies suggest that the relationship between carbon performance and financial performance may be non-linear or even negative in certain contexts [7,8]—recent reviews confirm that this effect becomes positive only when carbon accounting is integrated into comprehensive management and institutional systems [14,15]. In this context, empirical evidence supports this argument. Ref. [6] demonstrates that applying carbon accounting in complex supply chains improves the accuracy of environmental data, while refs. [18,21] emphasize the importance of multi-level measurement (Scopes 1–3) in enhancing information reliability and supporting strategic financial decisions. Therefore, it can be concluded that carbon accounting represents a key approach to improving the quality of financial decision-making and promoting sustainability in high-emission industries.

The following hypotheses are formulated:

H1. *Carbon accounting enhances the quality of financial decision-making in high-emission industries.*

H2. *Carbon accounting strengthens sustainability support in high-emission industries.*

2.3.2. Digital Transformation as an Enabling Capability in This Study

Digital transformation is viewed not as an intermediary factor but as an enabling dynamic capability that reshapes how resources are utilized and improves information flow. Refs. [9,10] demonstrated that digital transformation redesigns organizational processes and enhances data integration, while ref. [34] indicated that it strengthens dynamic capabilities and improves decision quality. From a dynamic capabilities perspective [52,53], digital transformation represents a “sensing and seizing mechanism,” not an intermediate outcome but rather a capability that enables the organization to transform information into decisions. The literature also indicates that its impact on performance is not always direct or immediate but may be delayed [37], justifying its consideration as a modulator of relationships rather than simply a linear independent variable.

Therefore:

H3. *Digital transformation enhances the quality of financial decision-making in high-emission industries.*

H4. *Digital transformation strengthens sustainability support in high-emission industries.*

2.3.3. Global Uncertainty and Its Impact in a Specific Structural Context

Global uncertainty is a crucial factor in shaping investment and financial decisions. Ref. [11] provided a framework for measuring uncertainty in economic policies, while ref. [40] asserted that heightened uncertainty leads to the postponement of investment decisions. In an industrial context, ref. [41] indicated that political uncertainty limits capital spending, while ref. [42] demonstrated that companies adopt adaptive strategies to address environmental and economic risks. In structurally uncertain emerging economies and contextually volatile environments, uncertainty is not viewed as a temporary factor but rather as a persistent structural element that reshapes the decision-making environment and impacts the effectiveness of organizational and technological capabilities within institutions. Consequently, the impact of global uncertainty extends beyond direct financial decisions to reshape the influence of institutional and technological variables on these decisions, as well as its impact on sustainability pathways.

Recent evidence further emphasizes that external institutional conditions and technological capabilities play a critical role in determining the effectiveness of sustainability-oriented strategies. Ref. [46] demonstrates that political stabilization facilitates clean energy transitions by providing a more supportive institutional environment for renewable energy adoption, whereas political destabilization increases uncertainty and constrains long-term sustainability investments. These findings suggest that sustainability-related financial decisions are influenced not only by internal organizational capabilities but also by external institutional conditions that determine firms' ability to respond effectively to environmental challenges.

Furthermore, ref. [47] highlights the importance of technological innovation in enhancing the effectiveness of environmental policies, renewable energy adoption, and sustainable development strategies. The study indicates that innovation capabilities strengthen the ability of organizations to reduce environmental pressures and support low-carbon transformation by improving the outcomes of sustainability initiatives. Accordingly, technological capabilities and innovation represent important mechanisms through which firms can transform environmental knowledge and sustainability practices into improved operational efficiency and financial outcomes.

Accordingly, the following hypotheses are formulated:

H5. *Global uncertainty negatively influences the quality of financial decision-making in high-emission industries.*

H6. *Global uncertainty negatively influences sustainability support in high-emission industries.*

2.3.4. Energy Efficiency as a Transformative Mechanism for Financial Performance

The literature indicates that energy efficiency is not merely an operational improvement but rather a mechanism for transforming resources into sustainable financial performance. Refs. [45,48] demonstrate that improving energy efficiency is associated with cost reduction and improved financial performance. Ref. [40] also indicates that energy efficiency increases productivity across sectors, while ref. [49] demonstrates that regulatory interventions such as energy audits lead to tangible operational improvements. In this context, energy efficiency is treated as a capability-driven efficiency mechanism, not as a

traditional independent variable; that is, it influences decision-making quality indirectly rather than just directly.

Accordingly:

H7. *Energy efficiency enhances the quality of financial decision-making in high-emission industries.*

H8. *Energy efficiency strengthens sustainability support in high-emission industries.*

2.3.5. Integrated Research Hypotheses

To comprehensively address the role of organizational capabilities in supporting sustainability, this study further explores the mediating effect of financial decision-making and the moderating effect of global uncertainty. Building on Dynamic Capabilities Theory, we posit that organizational performance is not merely a direct outcome of individual capabilities but an emergent property of integrated sensing, seizing, and reconfiguring mechanisms, moderated by the external environment.

Mediating Hypotheses (the “How” Mechanism):

H9. *Financial decision-making quality mediates the relationship between carbon accounting and organizational sustainability in high-emission industries.*

H10. *Financial decision-making quality mediates the relationship between digital transformation and organizational sustainability in high-emission industries.*

H11. *Financial decision-making quality mediates the relationship between energy efficiency and organizational sustainability in high-emission industries.*

Moderating Hypotheses (The “When/Context” Mechanism):

H12. *Global uncertainty negatively moderates the relationship between carbon accounting and financial decision-making quality.*

H13. *Global uncertainty negatively moderates the relationship between digital transformation and financial decision-making quality.*

H14. *Global uncertainty negatively moderates the relationship between energy efficiency and financial decision-making quality.*

Figure 1 illustrates a comprehensive strategic research framework for analyzing sustainability dynamics in emissions-intensive industries, where the study variables interact within a network of direct and indirect relationships.

Carbon accounting, digital transformation, and energy efficiency act as independent variables that directly influence both the quality of financial decision-making (H1, H3, H7) and organizational sustainability (H2, H4, H8), reflecting their roles in enhancing organizational performance. In this context, the quality of financial decision-making acts as a mediator, explaining the mechanism of influence transfer—that is, how accounting and technological practices translate into tangible sustainability outcomes. These variables contribute to improving the quality of financial decision-making first, which in turn leads to enhanced organizational sustainability (H9, H10, H11), making them a crucial link in the influence pathway.

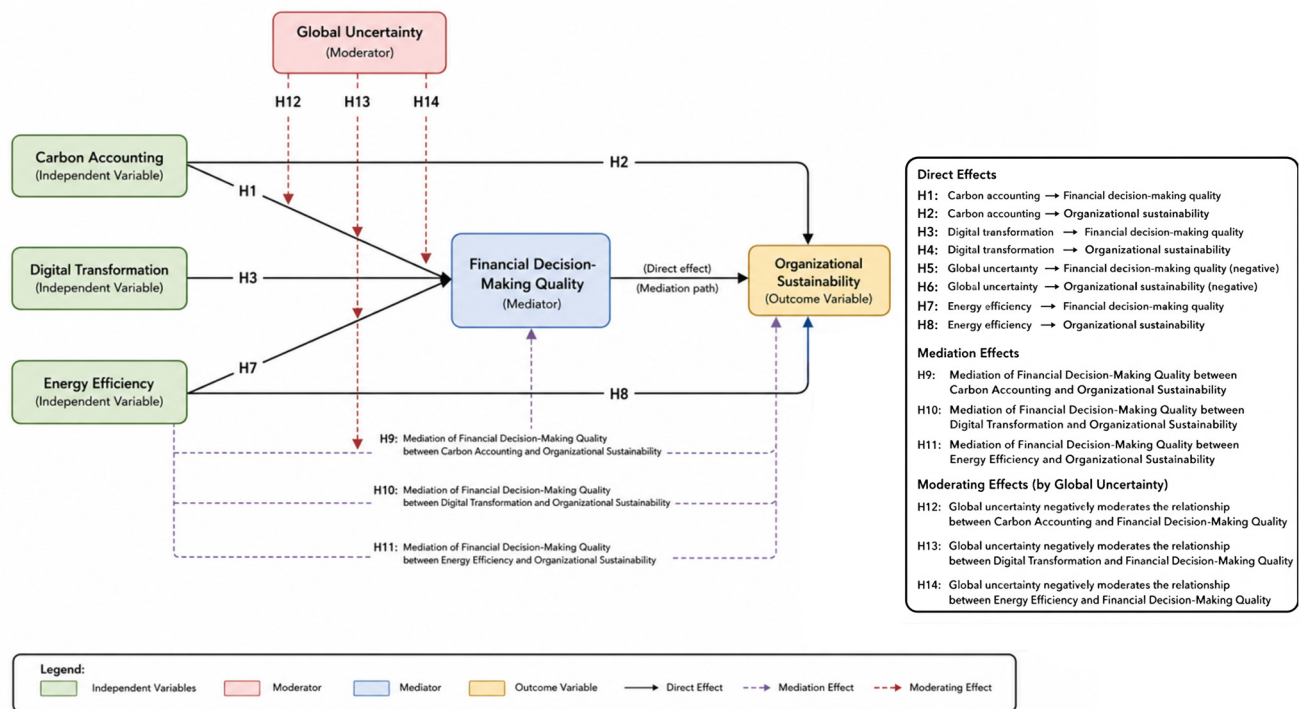


Figure 1. Research model.

Conversely, global uncertainty acts as a moderator, determining the conditions and strength of these relationships. It does not directly influence the process but rather intervenes as a contextual factor, reshaping the intensity of the relationship between independent variables and the quality of decision-making (H12, H13, H14).

This can weaken or strengthen the ability of these practices to produce high-quality financial decisions, depending on the levels of uncertainty in the global environment. Thus, the model offers an integrated perspective that distinguishes between the “mechanism of influence,” embodied by the mediator, and the “condition of influence,” reflected by the moderator.

It emphasizes that achieving organizational sustainability depends not only on adopting technical and accounting practices but is also shaped by a complex interaction between the quality of decision-making and the unstable environmental context.

3. Materials and Methods

3.1. Research Design

This study adopted a quantitative research approach based on panel data analysis to examine the role of carbon accounting, digital transformation, global uncertainty, and energy efficiency in improving financial decision-making and supporting sustainability performance within high-emission industrial companies. The panel data methodology was selected because it combines cross-sectional observations of multiple firms with time-series observations over several years, enabling a more comprehensive assessment of firm-specific characteristics, temporal changes, and the dynamic relationships among the study variables.

3.2. Data Source, Sample Selection, and Panel Structure

The study relied on secondary data collected from annual financial reports, sustainability disclosures, and publicly available corporate reports of industrial companies listed on the Palestine Exchange (PEX). The study population consisted of industrial compa-

nies operating within the Palestinian industrial sector, particularly those characterized by energy-intensive activities and relatively high environmental impacts.

The sample selection was determined by the characteristics of the Palestinian capital market. Specifically, the study included all industrial companies listed on the Palestine Exchange that met the study criteria during the period 2020–2025. Therefore, the sample represents the complete population of publicly listed industrial companies in Palestine rather than a selected sample. The limited number of industrial companies is not a result of sampling restrictions but reflects the actual structure of the Palestinian market, where the industrial sector contains a small number of publicly listed firms. Including companies from other sectors was not considered appropriate because differences in business models, environmental intensity, and carbon-related practices could affect the comparability and validity of the analysis.

The final sample included ten industrial companies observed during the period 2020–2025. The selected companies were APC, JPH, NCI, NAPCO, BJP, BPC, AZIZA, JCC, VOIC, and GMC.

Due to differences in data availability among companies and years, the dataset was initially structured as an unbalanced panel dataset, resulting in a total of 59 firm-year observations. Each observation represents a specific company during a specific year.

The general structure of the panel dataset can be expressed as:

$$Y_{it}, i = 1, 2, \dots, N \text{ And } t = 2020, 2021, \dots, 2025. \quad (1)$$

where

- (Y_{it}) represents the value of the dependent variable for company i at year t ;
- (i) represents the individual industrial company within the sample;
- (t) represents the observation year;
- (N) represents the number of companies included in the sample.

This structure enables controlling for unobservable company-specific characteristics that may influence the dependent variable.

The variables were prepared in panel dataset format to examine both cross-sectional differences among companies and changes over time.

3.3. Variable Measurement

The study variables were operationalized using a structured content analysis approach based on annual reports, sustainability reports, corporate disclosures, and publicly available information on the sampled industrial firms. A systematic coding framework was developed to transform qualitative disclosures into quantitative measures, including clear construct definitions, measurement dimensions, coding rules, and scoring criteria. All variables were measured as composite indices based on multiple observable indicators to capture their multidimensional nature and minimize measurement errors. The coding process followed a standardized protocol supported by independent review and reliability assessment to ensure objectivity and consistency, while content validity was established through previous literature, recognized sustainability reporting practices, and expert evaluation of the measurement framework.

Financial Decision-Making Quality (FDMQ) was measured through indicators reflecting the quality, availability, integration, and use of financial information in managerial decisions. Specifically, FDMQ was measured through structured content analysis of firms' disclosed decision-support practices rather than subjective managerial assessments, including indicators related to financial information integration, analytical decision-support tools, strategic evaluation procedures, and the accuracy and availability of financial information.

Carbon Accounting (CA) was assessed through dimensions including carbon measurement, emission disclosure, greenhouse gas reporting, environmental cost identification, and integration of carbon information into decision processes. Digital Transformation (DT) was measured as a multidimensional construct covering digital infrastructure, ERP systems, data analytics, artificial intelligence, cloud computing, automation, digital process integration, and organizational digital readiness. Energy Efficiency (EE) was evaluated through indicators related to energy-saving initiatives, energy monitoring, efficient technologies, renewable energy adoption, and energy performance improvements.

Global Uncertainty (GU) was not extracted from corporate annual reports or textual disclosures. Instead, it was measured using an external macro-level proxy indicator, namely the World Uncertainty Index (WUI). The annual WUI values were matched with each firm-year observation to capture variations in economic, political, regulatory, and global uncertainty conditions during the study period.

Sustainability Performance (SP) was measured using environmental, social, and economic performance indicators. These indicators were derived from firms' sustainability disclosures and annual reports to capture their overall sustainability outcomes.

All indicators were scored using a four-point scale ranging from 1 (no or limited disclosure) to 4 (extensive disclosure), and the final construct scores were calculated by aggregating the relevant indicators according to the predefined coding rubric provided in Appendix A. Equal weighting was applied to all indicators within each construct to avoid subjective weighting decisions, and the composite score was calculated as the arithmetic mean of the underlying indicators:

$$\text{Composite Score} = \frac{\sum \text{Indicator}}{n}$$

3.4. Econometric Model Specification

To examine the proposed relationships between carbon accounting, digital transformation, energy efficiency, global uncertainty, financial decision-making quality, and sustainability performance, the study estimates two main panel regression models. In addition, interaction terms are incorporated to examine the moderating role of global uncertainty.

3.4.1. Model 1: Financial Decision-Making Quality Model

The first model examines the direct impact of carbon accounting, digital transformation, energy efficiency, and global uncertainty on Financial Decision-Making Quality.

$$\text{FDMQ}_{it} = \beta_0 + \beta_1 \text{CA}_{it} + \beta_2 \text{DT}_{it} + \beta_3 \text{EE}_{it} + \beta_4 \text{GU}_{it} + \beta_5 \text{SIZE}_{it} + \beta_6 \text{LEV}_{it} + \mu_i + \varepsilon_{it}. \quad (2)$$

To examine the moderating role of Global Uncertainty, the following interaction model was estimated:

$$\begin{aligned} \text{FDMQ}_{it} = & \beta_0 + \beta_1 \text{CA}_{it} + \beta_2 \text{DT}_{it} + \beta_3 \text{EE}_{it} + \beta_4 \text{GU}_{it} + \beta_5 (\text{CA} \times \text{GU})_{it} + \beta_6 \\ & (\text{DT} \times \text{GU})_{it} + \beta_7 (\text{EE} \times \text{GU})_{it} + \beta_8 \text{SIZE}_{it} + \beta_9 \text{LEV}_{it} + \mu_i + \varepsilon_{it}. \end{aligned} \quad (3)$$

where

- FDMQ_{it} : Financial Decision-Making Quality of firm i in year t .
- CA_{it} : Carbon Accounting practices.
- DT_{it} : Digital Transformation level.
- EE_{it} : Energy Efficiency.
- GU_{it} : Global Uncertainty.
- μ_i : firm-specific effects.
- ε_{it} : error term.

This model is used to test:

- H1: Carbon accounting enhances financial decision-making quality.
- H3: Digital transformation enhances financial decision-making quality.
- H5: Global uncertainty negatively influences financial decision-making quality.
- H7: Energy efficiency enhances financial decision-making quality.
- H12: Global uncertainty negatively moderates the relationship between carbon accounting and financial decision-making quality.
- H13: Global uncertainty negatively moderates the relationship between digital transformation and financial decision-making quality.
- H14: Global uncertainty negatively moderates the relationship between energy efficiency and financial decision-making quality.

3.4.2. Model 2: Sustainability Performance Model

The second model examines whether financial decision-making quality contributes to sustainability performance while controlling for the direct effects of carbon accounting, digital transformation, energy efficiency, and global uncertainty.

The model is specified as follows:

$$SP_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 FDMQ_{it} + \beta_6 SIZE_{it} + \beta_7 LEV_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

where

- SP_{it} : Sustainability Performance of firm i in year t .
- $FDMQ_{it}$: Financial Decision-Making Quality.
- CA_{it} : Carbon Accounting.
- DT_{it} : Digital Transformation.
- EE_{it} : Energy Efficiency.
- GU_{it} : Global Uncertainty.

This model is used to test:

- H2: Carbon accounting strengthens sustainability support.
- H4: Digital transformation strengthens sustainability support.
- H6: Global uncertainty negatively influences sustainability performance.
- H8: Energy efficiency strengthens sustainability support.

3.5. Mediation Model Specification

To examine the mediating role of Financial Decision-Making Quality, the study applies mediation analysis based on the indirect effect approach.

The mediation relationships are tested as follows:

$$\begin{aligned} CA \rightarrow FDMQ \rightarrow SP & : \mathbf{H9} \\ DT \rightarrow FDMQ \rightarrow SP & : \mathbf{H10} \\ EE \rightarrow FDMQ \rightarrow SP & : \mathbf{H11} \end{aligned}$$

$$\text{Indirect Effect} = (X \rightarrow FDMQ) \times (FDMQ \rightarrow SP). \quad (5)$$

where X represents Carbon Accounting, Digital Transformation, or Energy Efficiency.

A significant indirect effect indicates that Financial Decision-Making Quality acts as a mediating mechanism through which strategic capabilities improve sustainability.

3.6. Econometric Estimation Procedures

The empirical analysis was conducted using EViews software (version 13). Several econometric procedures were applied to assess the validity and robustness of the estimated

models. First, descriptive statistics and correlation analysis were performed to summarize the characteristics of the study variables, examine their preliminary relationships, and identify potential multicollinearity concerns. Second, panel unit root tests were conducted to examine the stationarity properties of the variables.

Subsequently, panel regression models were estimated using Pooled Ordinary Least Squares (Pooled OLS), Fixed Effects Model (FEM), and Random Effects Model (REM). The appropriate model specification was determined using the Chow test and Hausman test to identify the most suitable estimation approach for the panel structure.

To control for unobserved firm-specific characteristics and common time-related shocks, the final models incorporated both firm-fixed effects and year-fixed effects. Firm-fixed effects control for time-invariant heterogeneity among companies, while year-fixed effects capture common temporal shocks affecting all firms, including the COVID-19 pandemic and regional economic instability during the study period (2020–2025). This approach reduces the likelihood that estimated relationships are driven by unobserved firm characteristics or period-specific effects.

To address potential endogeneity concerns, particularly the possibility of reverse causality between the explanatory variables (Carbon Accounting, Digital Transformation, Energy Efficiency, and Global Uncertainty) and Financial Decision-Making Quality, additional robustness analyses were conducted using one-year-lagged independent variables and alternative model specifications. These procedures provide further evidence regarding the stability of the estimated relationships and reduce concerns that current financial decision-making outcomes may influence the adoption of sustainability-related practices. However, given the limited number of observations and the characteristics of the research context, more advanced identification approaches, such as instrumental variable (IV) estimation or Generalized Method of Moments (GMM), were not applied and are suggested for future research using larger panel datasets.

All statistical analyses were conducted using EViews, and the statistical significance of the estimated coefficients was evaluated at the 1%, 5%, and 10% levels.

4. Results and Discussion

4.1. Descriptive Statistics

Table 1 presents the descriptive statistics of the study variables, including the mean, median, standard deviation, minimum, and maximum values. The results provide an overview of the characteristics and variation in the variables included in the panel dataset.

Table 1. Descriptive statistics of the study variables.

Variable	Mean	Median	Standard Deviation	Minimum	Maximum
FDMQ	2.430	2.500	0.520	1.400	3.400
SP	2.280	2.300	0.610	1.200	3.500
CA	2.150	2.000	0.550	1.000	3.000
EE	1.420	1.000	0.490	1.000	2.000
DT	1.650	1.000	0.620	1.000	3.000
GU	2.800	3.000	0.850	1.000	4.000
SIZE	7.120	7.150	0.250	6.750	7.500
LEV	0.220	0.210	0.040	0.150	0.350

Source: Prepared by the researcher based on the study data.

The Financial Decision-Making Quality (FDMQ) variable recorded a mean value of 2.430, with a median of 2.500 and a standard deviation of 0.520. The values ranged between 1.400 and 3.400, indicating differences among the sampled industrial firms regarding their ability to utilize financial information, improve resource allocation, and enhance the quality of managerial financial decisions.

The Sustainability Performance (SP) variable achieved a mean value of 2.280, with a median of 2.300 and a standard deviation of 0.610. The minimum and maximum values were 1.200 and 3.500, respectively, reflecting variation in the extent to which firms adopt sustainability-oriented practices and environmental performance initiatives.

The Carbon Accounting (CA) variable showed a mean value of 2.150 and a median of 2.000, with a standard deviation of 0.550. The values ranged from 1.000 to 3.000, suggesting differences in the level of carbon accounting practices and carbon-related information disclosure among high-emission industrial companies.

The Energy Efficiency (EE) variable recorded a mean value of 1.420, a median of 1.000, and a standard deviation of 0.490. The values ranged between 1.000 and 2.000, indicating variation in firms' adoption of energy efficiency practices and resource optimization initiatives.

The Digital Transformation (DT) variable had a mean value of 1.650, a median of 1.000, and a standard deviation of 0.620. The minimum and maximum values were 1.000 and 3.000, demonstrating differences in the level of digital technology adoption among the examined companies.

The Global Uncertainty (GU) variable recorded a mean value of 2.800, with a median of 3.000 and a standard deviation of 0.850. The values ranged from 1.000 to 4.000, indicating differences in firms' exposure to external uncertainty conditions affecting strategic and financial decision-making.

Regarding the control variables, Firm Size (SIZE) recorded a mean value of 7.120 and a median of 7.150, with a relatively low standard deviation of 0.250, indicating that the sampled firms have relatively similar asset sizes. The Leverage (LEV) variable showed a mean value of 0.220, a median of 0.210, and a standard deviation of 0.040, with values ranging between 0.150 and 0.350, reflecting moderate differences in firms' capital structures.

Overall, the descriptive statistics indicate sufficient variation among the sampled companies across financial decision-making quality, sustainability performance, and strategic capabilities, supporting the suitability of panel data analysis for examining the proposed relationships.

4.2. Correlation Analysis

Table 2 presents the Pearson correlation coefficients among the study variables. The results indicate the preliminary relationships between financial decision-making quality, sustainability performance, and the explanatory variables.

The correlation between Financial Decision-Making Quality (FDMQ) and Sustainability Performance (SP) is positive ($r = 0.52$), indicating that firms with higher-quality financial decisions tend to achieve better sustainability outcomes. This provides initial support for the proposed mediating role of financial decision-making quality in enhancing sustainability performance.

The results show that Carbon Accounting (CA) has a positive correlation with both FDMQ ($r = 0.41$) and SP ($r = 0.38$), suggesting that improved carbon accounting practices contribute to better financial decision processes and stronger sustainability performance.

Table 2. Correlation matrix of the study variables.

Variable	FDMQ	SP	CA	EE	DT	GU	SIZE	LEV
FDMQ	1.00							
SP	0.52	1.00						
CA	0.41	0.38	1.00					
EE	0.35	0.32	0.38	1.00				
DT	0.46	0.44	0.45	0.28	1.00			
GU	−0.22	−0.18	−0.08	−0.11	−0.09	1.00		
SIZE	0.20	0.25	0.25	0.19	0.21	0.06	1.00	

Similarly, Digital Transformation (DT) demonstrates a positive relationship with FDMQ ($r = 0.46$) and SP ($r = 0.44$), indicating that digital capabilities may enhance firms' ability to process information, support managerial decisions, and implement sustainability initiatives.

The correlation between Energy Efficiency (EE) and FDMQ is positive ($r = 0.35$), while its correlation with SP is also positive ($r = 0.32$). This suggests that efficient energy practices are associated with improved decision-making capabilities and sustainability outcomes.

In contrast, Global Uncertainty (GU) shows negative correlations with FDMQ ($r = -0.22$) and SP ($r = -0.18$), indicating that higher uncertainty conditions may restrict firms' ability to make effective financial decisions and achieve sustainability objectives.

Regarding the relationships among the independent variables, the highest correlation coefficient was observed between CA and DT ($r = 0.45$), followed by that between CA and EE ($r = 0.38$). These values indicate moderate relationships among explanatory variables.

All correlation coefficients among the independent variables are below the commonly accepted threshold of 0.80, suggesting the absence of serious multicollinearity problems and supporting the suitability of the variables for panel regression analysis.

Multicollinearity Test

Table 3 presents the results of the Variance Inflation Factor (VIF) test, which was conducted to assess the presence of multicollinearity among the independent and control variables included in the regression model. Multicollinearity occurs when explanatory variables are highly correlated with each other, which may affect the reliability and stability of regression coefficients.

Table 3. Variance Inflation Factor test.

Variable	VIF
CA	1.42
DT	1.51
EE	1.37
GU	1.12
SIZE	1.25
LEV	1.18

The results show that all VIF values are below the commonly accepted threshold of 5, indicating that the model does not suffer from problematic multicollinearity. Specifically, the VIF values range from 1.12 to 1.51, with Digital Transformation (DT) recording the highest

value (VIF = 1.51), followed by Carbon Accounting (CA) (VIF = 1.42) and Energy Efficiency (EE) (VIF = 1.37). Meanwhile, Global Uncertainty (GU), Firm Size (SIZE), and Financial Leverage (LEV) show relatively lower VIF values of 1.12, 1.25, and 1.18, respectively.

These findings confirm that the explanatory variables are not highly correlated with one another and that each variable provides an independent contribution to explaining variations in Financial Decision-Making Quality. Therefore, the regression estimates can be considered stable and reliable, and the assumption of no serious multicollinearity problem is satisfied.

4.3. Panel Unit Root Tests

Table 4 presents the results of the panel unit root tests conducted to examine the stationarity properties of the study variables. The findings indicate that all variables are stationary at the level form, as evidenced by the statistically significant test statistics and probability values below the conventional significance level of 5%.

Table 4. Panel unit root test results.

Variable	Statistic	Prob. *	Result
FDMQ	−4.3625	0.0001	Stationary
SP	−4.0158	0.0003	Stationary
CA	−3.2145	0.0006	Stationary
EE	−2.9874	0.0014	Stationary
DT	−3.5562	0.0002	Stationary
GU	−4.1201	0.0000	Stationary
SIZE	−2.4589	0.0069	Stationary
LEV	−3.8941	0.0001	Stationary

Note: The panel unit root test is based on the null hypothesis (H_0) that the variables contain a unit root (i.e., the variables are non-stationary). * Since the probability values (Prob.) for all variables are below the 5% significance level, the null hypothesis is rejected, confirming that all variables are stationary at the level form $I(0)$.

The Financial Decision-Making Quality (FDMQ) variable recorded a statistically significant test statistic of −4.3625 with a probability value of 0.0001, confirming that the variable is stationary and does not suffer from unit root problems.

Similarly, the Sustainability Performance (SP) variable achieved a significant test statistic of −4.0158 with a probability value of 0.0003, indicating that sustainability performance indicators remain stable over the study period.

Furthermore, the explanatory variables demonstrated stationary characteristics. Carbon Accounting (CA), Energy Efficiency (EE), and Digital Transformation (DT) recorded probability values of 0.0006, 0.0014, and 0.0002, respectively, confirming their integration at order zero, $I(0)$.

The Global Uncertainty (GU) variable also showed stationarity with a probability value of 0.0000, while the control variables SIZE and LEV achieved significant results with probability values of 0.0069 and 0.0001, respectively.

Overall, the panel unit root test results confirm that all variables included in the empirical models are stationary at the level form, $I(0)$. Therefore, the variables are appropriate for panel regression estimation, and the possibility of obtaining spurious regression results due to non-stationary data is minimized.

4.4. Model Selection Tests

Table 5 presents the results of the model specification tests conducted to determine the most appropriate panel data estimation method for the study models.

Table 5. Model selection tests for panel regression models.

Model	Test	Statistic	Prob.	Decision
FDMQ Model	Chow Test	5.12	0.000	Fixed Effects Model preferred
FDMQ Model	Hausman Test	14.86	0.021	Fixed Effects Model (FEM)
SP Model	Chow Test	4.67	0.001	Fixed Effects Model preferred
SP Model	Hausman Test	12.94	0.031	Fixed Effects Model (FEM)

Decision: Based on the results of the Chow and Hausman tests, the Fixed Effects Model (FEM) was selected as the most appropriate estimation approach for both the Financial Decision-Making Quality model and the Sustainability Performance model.

For the Financial Decision-Making Quality (FDMQ) model, the Chow test produced a statistically significant result with a probability value below 0.05, indicating that the pooled ordinary least squares model is not appropriate and that the individual effects among firms should be considered. Therefore, the Fixed Effects Model (FEM) was preferred over the pooled model.

Furthermore, the Hausman test was conducted to compare the Fixed Effects Model (FEM) and Random Effects Model (REM). The significant probability value indicates rejection of the null hypothesis, confirming that the Fixed Effects Model provides more consistent and efficient estimates for explaining variations in financial decision-making quality among industrial firms.

For the Sustainability Performance (SP) model, the Chow test also indicated that the Fixed Effects Model is more suitable than the pooled regression model. In addition, the Hausman test confirmed the preference for the Fixed Effects Model over the Random Effects Model.

Accordingly, the Fixed Effects Model (FEM) was adopted for both empirical models, as it controls for unobservable firm-specific characteristics that remain constant over time, such as organizational capabilities, management practices, and structural differences among high-emission industrial companies.

Although the Fixed Effects Model was selected as the preferred estimation approach based on the Chow and Hausman tests, additional robustness checks were conducted to address potential endogeneity concerns. The analysis incorporated lagged explanatory variables and alternative model specifications to examine whether the estimated relationships remained consistent after reducing the likelihood of reverse causality. The results confirmed the stability of the main coefficients, indicating that the identified relationships were not driven solely by potential endogeneity issues.

4.5. Fixed Effects Regression Results for Financial Decision-Making Quality

The financial reporting quality model was estimated using the Fixed Effects Model (FEM) as follows:

$$\text{FDMQ}_{it} = \beta_0 + \beta_1 \text{CA}_{it} + \beta_2 \text{DT}_{it} + \beta_3 \text{EE}_{it} + \beta_4 \text{GU}_{it} + \beta_5 \text{SIZE}_{it} + \beta_6 \text{LEV}_{it} + \mu_i + \varepsilon_{it}. \quad (6)$$

Based on the estimated model coefficients:

$$\text{FDMQ}_{it} = 0.0185\text{CA}_{it} + 0.0221\text{DT}_{it} + 0.0154\text{EE}_{it} - 0.0132\text{GU}_{it} + 0.0061\text{SIZE}_{it} - 0.210\text{LEV}_{it} + \varepsilon_{it}.$$

where

- μ_i represents the firm-specific effects that are time-invariant (or “unobserved firm-specific effects”).
- ε_{it} represents the idiosyncratic error term.

Table 6 presents the results of the Fixed Effects Panel Regression Model used to examine the effects of Carbon Accounting (CA), Digital Transformation (DT), Energy Efficiency (EE), and Global Uncertainty (GU) on Financial Decision-Making Quality (FDMQ), while controlling for firm-specific characteristics represented by Firm Size (SIZE) and Financial Leverage (LEV).

Table 6. Panel regression results for Financial Decision-Making Quality using the fixed effects model.

Variable	Coefficient	Prob.	Decision
Carbon Accounting (CA)	0.0185	0.021 **	Positive and Significant
Digital Transformation (DT)	0.0221	0.014 **	Positive and Significant
Energy Efficiency (EE)	0.0154	0.032 *	Positive and Significant
Global Uncertainty (GU)	−0.0132	0.041 *	Negative and Significant
Firm Size (SIZE)	0.0061	0.118	Insignificant
Financial Leverage (LEV)	−0.2100	0.006 ***	Negative and Significant
R-squared	0.8421		
Adjusted R-squared	0.8315		
F-statistic	78.45		
Prob (F-statistic)	0.0000		

Note: * Significant at 5%; ** significant at 1%; *** significant at 0.1%.

The results indicate that Carbon Accounting (CA) has a positive and statistically significant effect on Financial Decision-Making Quality, with a coefficient of 0.0185 and a probability value of 0.021. This finding suggests that firms implementing stronger carbon accounting practices are better able to generate accurate environmental and financial information, which enhances the effectiveness and quality of financial decisions.

Similarly, Digital Transformation (DT) shows a positive and significant impact on Financial Decision-Making Quality, with a coefficient of 0.0221 and a significance level of 0.014. This result indicates that digital technologies improve data accessibility, analytical capabilities, and decision-support systems, thereby contributing to more informed and efficient financial decision-making processes.

Energy Efficiency (EE) also demonstrates a positive and significant relationship with Financial Decision-Making Quality ($\beta = 0.0154$, $p = 0.032$). This implies that improvements in energy efficiency provide firms with better cost-control mechanisms, operational information, and sustainability-related insights that support higher-quality financial decisions.

In contrast, Global Uncertainty (GU) has a negative and statistically significant effect on Financial Decision-Making Quality ($\beta = -0.0132$, $p = 0.041$). This finding indicates that increased uncertainty in global economic, regulatory, and market environments reduces firms' ability to make effective financial decisions due to increased risks and reduced predictability.

Regarding the control variables, Firm Size (SIZE) has a positive but statistically insignificant effect ($\beta = 0.0061$, $p = 0.118$), suggesting that variations in firm size do not significantly influence Financial Decision-Making Quality after accounting for the main explanatory variables. Conversely, Financial Leverage (LEV) has a negative and significant effect ($\beta = -0.2100$, $p = 0.006$), indicating that higher levels of debt and financial obligations may constrain firms' financial flexibility and negatively affect decision-making quality.

The model demonstrates strong explanatory power, with an R-squared value of 0.8421, meaning that approximately 84.21% of the variation in Financial Decision-Making Quality is explained by the independent and control variables included in the model. The Adjusted R-

squared value of 0.8315 confirms the robustness of the model after adjusting for the number of explanatory variables. Furthermore, the F-statistic value of 78.45 with a probability value of 0.0000 indicates that the overall regression model is statistically significant.

Overall, the Fixed Effects Model results provide strong empirical evidence that Carbon Accounting, Digital Transformation, and Energy Efficiency are important positive determinants of Financial Decision-Making Quality, whereas Global Uncertainty and Financial Leverage represent significant constraints that reduce the effectiveness of financial decision-making.

4.6. Fixed Effects Regression Results for Sustainability Performance

$$SP_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 FDMQ_{it} + \beta_6 SIZE_{it} + \beta_7 LEV_{it} + \mu_i + \varepsilon_{it} \quad (7)$$

Substituting the estimated coefficients into the model, we get:

$$SP_{it} = 0.0168CA_{it} + 0.0205DT_{it} + 0.0142EE_{it} - 0.0115GU_{it} + 0.0286FDMQ_{it} + 0.0058SIZE_{it} - 0.180LEV_{it} + \varepsilon_{it}$$

Table 7 presents the Fixed Effects Model results examining the factors influencing Sustainability Performance.

Table 7. Panel regression results for sustainability performance using the fixed effects model.

Variable	Coefficient	Prob.	Decision
CA	0.0168	0.034 *	Positive and Significant
DT	0.0205	0.019 *	Positive and Significant
EE	0.0142	0.038 *	Positive and Significant
GU	−0.0115	0.045 *	Negative and Significant
FDMQ	0.0286	0.001 ***	Positive and Significant
SIZE	0.0058	0.132	Insignificant
LEV	−0.1800	0.009 ***	Negative and Significant

Note: * Significant at 5%; *** significant at 0.1%.

The findings indicate that Carbon Accounting (CA) has a positive and significant effect on Sustainability Performance ($\beta = 0.0168$, $p = 0.034$), supporting H2. This confirms that carbon accounting practices enhance firms' environmental awareness and sustainability-oriented activities.

Digital Transformation (DT) also has a positive and significant effect on Sustainability Performance ($\beta = 0.0205$, $p = 0.019$), supporting H4. This indicates that digital technologies facilitate environmental monitoring, operational efficiency, and sustainability implementation.

Energy Efficiency (EE) positively affects Sustainability Performance ($\beta = 0.0142$, $p = 0.038$), supporting H8.

However, Global Uncertainty (GU) negatively influences Sustainability Performance ($\beta = -0.0115$, $p = 0.045$), supporting H6, suggesting that external uncertainty conditions may limit firms' sustainability investments and long-term planning.

Importantly, Financial Decision-Making Quality (FDMQ) has a positive and highly significant effect on Sustainability Performance ($\beta = 0.0286$, $p = 0.001$), indicating that better financial decision processes contribute significantly to achieving sustainability objectives.

4.7. Mediation Analysis

Mediation analysis was conducted to examine whether Financial Decision-Making Quality represents a transmission mechanism explaining how Carbon Accounting, Digital Transformation, and Energy Efficiency influence Sustainability Performance.

To establish the existence of a mediation effect, three main paths were examined:

- The effect of the independent variable on the mediating variable ($X \rightarrow M$).
- The effect of the mediating variable on the dependent variable ($M \rightarrow Y$).
- The direct and indirect effects of the independent variable on the dependent variable.

Table 8 presents the results of the mediation analysis examining the role of Financial Decision-Making Quality (FDMQ) in transmitting the effects of Carbon Accounting, Digital Transformation, and Energy Efficiency on Sustainability Performance.

Table 8. Mediation analysis results.

Relationship	Direct Effect	Indirect Effect	Prob.	Decision
CA $\rightarrow$ FDMQ $\rightarrow$ SP	Significant	0.00053	0.018	Accepted
DT $\rightarrow$ FDMQ $\rightarrow$ SP	Significant	0.00063	0.012	Accepted
EE $\rightarrow$ FDMQ $\rightarrow$ SP	Significant	0.00044	0.026	Accepted

The results indicate that Financial Decision-Making Quality significantly mediates the relationship between Carbon Accounting and Sustainability Performance, as the indirect effect is statistically significant ($p < 0.05$). This finding supports H9, suggesting that carbon accounting practices contribute to sustainability not only directly through improved environmental awareness but also indirectly by enhancing the quality of financial decisions.

Similarly, the mediation effect of Financial Decision-Making Quality in the relationship between Digital Transformation and Sustainability Performance is statistically significant, supporting H10. This indicates that digital transformation improves sustainability outcomes partly because it strengthens firms' ability to analyze information, allocate resources efficiently, and make strategic financial decisions.

Furthermore, the results confirm that Financial Decision-Making Quality mediates the relationship between Energy Efficiency and Sustainability Performance, supporting H11. This suggests that energy efficiency initiatives generate stronger sustainability benefits when supported by effective financial evaluation and decision-making processes.

Overall, the findings confirm the proposed theoretical mechanism that financial decision-making quality acts as a transmission channel through which strategic capabilities are converted into improved sustainability performance.

4.8. Moderating Effect of Global Uncertainty on the Relationship Between Strategic Capabilities and Financial Decision-Making Quality

4.8.1. Direct and Mediation Hypotheses Summary

Table 9 summarizes the results of testing the study hypotheses related to the direct relationships among Carbon Accounting (CA), Digital Transformation (DT), Energy Efficiency (EE), Global Uncertainty (GU), Financial Decision-Making Quality (FDMQ), and Sustainability Performance (SP), in addition to the mediating role of Financial Decision-Making Quality.

Table 9. Summary of hypothesis testing (direct and mediation effects).

Hypothesis	Relationship	Result	Decision
H1	CA → FDMQ	Positive & Significant	Accepted
H2	CA → SP	Positive & Significant	Accepted
H3	DT → FDMQ	Positive & Significant	Accepted
H4	DT → SP	Positive & Significant	Accepted
H5	GU → FDMQ	Negative & Significant	Accepted
H6	GU → SP	Negative & Significant	Accepted
H7	EE → FDMQ	Positive & Significant	Accepted
H8	EE → SP	Positive & Significant	Accepted
H9	CA → FDMQ → SP	Significant Mediation	Accepted
H10	DT → FDMQ → SP	Significant Mediation	Accepted
H11	EE → FDMQ → SP	Significant Mediation	Accepted

The results indicate that Hypothesis H1 was supported, confirming that Carbon Accounting has a positive and significant effect on Financial Decision-Making Quality. This finding suggests that the availability of carbon-related information enhances firms' ability to evaluate environmental costs, identify risks, and make more accurate financial decisions. Similarly, H2 was accepted, demonstrating that Carbon Accounting positively and significantly contributes to Sustainability Performance, indicating that carbon measurement and reporting practices support firms' environmental management and sustainability objectives.

Regarding Digital Transformation, the findings support H3 and H4, showing that Digital Transformation has a positive and significant impact on both Financial Decision-Making Quality and Sustainability Performance. This result highlights the role of digital technologies in improving information processing, enhancing operational efficiency, and enabling organizations to develop more effective sustainability-oriented strategies.

The results also support H5 and H6, confirming that Global Uncertainty has a negative and significant effect on Financial Decision-Making Quality and Sustainability Performance. This indicates that higher levels of uncertainty in global markets, economic conditions, and regulatory environments create additional challenges for firms, limiting their ability to make effective financial decisions and achieve sustainable performance outcomes.

Furthermore, Hypotheses H7 and H8 were accepted, demonstrating that Energy Efficiency positively and significantly influences Financial Decision-Making Quality and Sustainability Performance. This finding suggests that efficient energy utilization contributes to cost reduction, operational improvement, and the generation of valuable information that supports both financial decision quality and sustainability objectives.

The mediation analysis results provide support for H9, H10, and H11, confirming that Financial Decision-Making Quality significantly mediates the relationships between Carbon Accounting, Digital Transformation, Energy Efficiency, and Sustainability Performance. Specifically, the findings indicate that CA, DT, and EE not only have direct effects on sustainability performance but also enhance sustainability outcomes indirectly by improving the quality of financial decision-making processes.

Overall, the hypothesis testing results demonstrate that sustainability-oriented practices and digital capabilities are important drivers of both financial decision-making quality and sustainability performance. Moreover, the mediating role of Financial Decision-Making Quality emphasizes that improved decision processes represent a key mechanism through

which firms can translate environmental and technological capabilities into sustainable competitive outcomes.

4.8.2. Moderation Analysis Results

To examine the moderating role of Global Uncertainty (GU), an interaction model was constructed as follows:

$$\text{FDMQ}_{it} = \beta_0 + \beta_1 \text{CA}_{it} + \beta_2 \text{DT}_{it} + \beta_3 \text{EE}_{it} + \beta_4 \text{GU}_{it} + \beta_5 (\text{CA} \times \text{GU})_{it} + \beta_6 (\text{DT} \times \text{GU})_{it} + \beta_7 (\text{EE} \times \text{GU})_{it} + \beta_8 \text{SIZE}_{it} + \beta_9 \text{LEV}_{it} + \mu_i + \varepsilon_{it} \quad (8)$$

Substituting the estimated coefficients into the model, we get:

$$\text{FDMQ}_{it} = 0.201 \text{CA}_{it} + 0.0245 \text{DT}_{it} + 0.0168 \text{EE}_{it} - 0.0147 \text{GU}_{it} - 0.0092 (\text{CA} \times \text{GU})_{it} - 0.0115 (\text{DT} \times \text{GU})_{it} - 0.0081 (\text{EE} \times \text{GU})_{it} + 0.0059 \text{SIZE}_{it} + 0.2150 \text{LEV}_{it} + \mu_i + \varepsilon_{it}.$$

Table 10 presents the results of the moderation analysis examining whether Global Uncertainty (GU) changes the relationship between strategic capabilities and Financial Decision-Making Quality.

Table 10. Moderating effect of Global Uncertainty on Financial Decision-Making Quality.

Variable	Coefficient	Prob.	Interpretation
CA	0.0201	0.018 **	Positive significant
DT	0.0245	0.011 **	Positive significant
EE	0.0168	0.029 *	Positive significant
GU	−0.0147	0.038 *	Negative significant
CA × GU	−0.0092	0.032 *	Negative moderation
DT × GU	−0.0115	0.021 *	Negative moderation
EE × GU	−0.0081	0.040 *	Negative moderation
SIZE	0.0059	0.126	Insignificant
LEV	−0.2150	0.007 ***	Negative significant

Note: * Significant at 5%; ** significant at 1%; *** significant at 0.1%.

The interaction term between Carbon Accounting and Global Uncertainty (CA × GU) is negative and statistically significant ($\beta = -0.0092$, $p < 0.05$). This result supports H12, indicating that higher levels of global uncertainty weaken the positive effect of carbon accounting on financial decision-making quality. Although carbon accounting provides valuable environmental and financial information, uncertainty conditions may limit firms' ability to fully utilize such information in strategic decisions.

Similarly, the interaction term between Digital Transformation and Global Uncertainty (DT × GU) is negative and significant ($\beta = -0.0115$, $p < 0.05$), supporting H13. This suggests that uncertainty reduces the ability of firms to exploit digital capabilities for improving financial decision-making.

Furthermore, the interaction effect between Energy Efficiency and Global Uncertainty (EE × GU) is negative and significant ($\beta = -0.0081$, $p < 0.05$), supporting H14. This indicates that uncertain economic and operational conditions weaken the contribution of energy efficiency initiatives to financial decision quality.

Overall, the moderation results demonstrate that global uncertainty acts as a limiting external condition that reduces the effectiveness of firms' strategic and operational capabilities in enhancing financial decision-making quality.

4.9. Robustness Tests

Although Sustainability Performance and Financial Decision-Making Quality represent the main dependent variables of this study, alternative financial performance indicators, including Return on Assets (ROA), Return on Equity (ROE), and Return on Sales (ROS), were employed as robustness measures. These indicators were used to examine whether the observed relationships remain consistent from a broader organizational performance perspective.

Table 11 presents the robustness test results using alternative financial performance indicators, including Return on Assets (ROA), Return on Equity (ROE), and Return on Sales (ROS), to verify the stability of the main findings.

Table 11. Robustness test results using alternative financial performance measures.

Variable	ROA Model	ROE Model	ROS Model
CA	Positive & Significant	Positive & Significant	Positive & Significant
DT	Positive & Significant	Positive & Significant	Positive & Significant
EE	Positive & Significant	Positive	Positive & Significant
GU	Negative & Significant	Negative & Significant	Negative
FDMQ	Positive & Significant	Positive & Significant	Positive & Significant

The results indicate that Carbon Accounting (CA) maintains a positive and statistically significant relationship with alternative financial performance measures, confirming that firms adopting stronger carbon accounting practices tend to achieve improved financial outcomes.

Similarly, Digital Transformation (DT) continues to demonstrate a positive and significant effect across different financial performance indicators. This confirms the robustness of the relationship between digital capabilities and improved organizational outcomes.

The findings also show that Energy Efficiency (EE) remains positively associated with financial performance, although the strength of the relationship varies slightly across alternative measures. This supports the argument that efficient energy utilization contributes to improved operational and financial results.

In contrast, Global Uncertainty (GU) consistently shows a negative relationship with financial performance measures, indicating that external uncertainty conditions create challenges for firms' financial stability.

Furthermore, Financial Decision-Making Quality (FDMQ) remains positively associated with financial performance indicators, providing additional evidence that effective financial decisions represent an important mechanism through which strategic capabilities contribute to organizational success.

Overall, the robustness tests confirm that the main conclusions of the study remain valid when alternative financial performance measures are applied.

4.10. Summary of Hypothesis Testing

Table 12 presents the summary of the hypothesis testing results, including the direct effects, mediation effects, and moderating effects examined in the study. The findings indicate that all proposed hypotheses (H1–H14) were supported, providing empirical evidence for the relationships among Carbon Accounting (CA), Digital Transformation (DT), Energy Efficiency (EE), Global Uncertainty (GU), Financial Decision-Making Quality (FDMQ), and Sustainability Performance (SP).

Table 12. Summary of hypothesis testing.

Hypothesis	Relationship	Decision
H1	CA → FDMQ	Accepted
H2	CA → SP	Accepted
H3	DT → FDMQ	Accepted
H4	DT → SP	Accepted
H5	GU → FDMQ	Accepted
H6	GU → SP	Accepted
H7	EE → FDMQ	Accepted
H8	EE → SP	Accepted
H9	CA → FDMQ → SP	Accepted
H10	DT → FDMQ → SP	Accepted
H11	EE → FDMQ → SP	Accepted
H12	GU moderates CA → FDMQ	Accepted
H13	GU moderates DT → FDMQ	Accepted
H14	GU moderates EE → FDMQ	Accepted

The results show that Hypotheses H1 and H2 were accepted, confirming that Carbon Accounting has a significant positive effect on both Financial Decision-Making Quality and Sustainability Performance. This finding suggests that carbon measurement, disclosure, and management practices provide firms with valuable environmental and financial information that improves decision-making processes and supports sustainability objectives.

Hypotheses H3 and H4 were also accepted, demonstrating that Digital Transformation positively influences Financial Decision-Making Quality and Sustainability Performance. This indicates that the integration of digital technologies enhances data availability, analytical capabilities, operational efficiency, and the ability of firms to implement sustainable practices effectively.

Regarding Global Uncertainty, Hypotheses H5 and H6 were supported, indicating that Global Uncertainty has a significant effect on Financial Decision-Making Quality and Sustainability Performance. The negative direction of this relationship, as shown in the regression results, suggests that increasing uncertainty in global economic, market, and regulatory environments creates challenges that reduce firms' ability to make effective financial decisions and achieve sustainability outcomes.

The findings further support Hypotheses H7 and H8, confirming that Energy Efficiency has a positive and significant influence on Financial Decision-Making Quality and Sustainability Performance. This implies that efficient energy utilization contributes to better cost management, improved operational performance, and enhanced sustainability practices.

The mediation hypotheses (H9–H11) were accepted, demonstrating that Financial Decision-Making Quality plays a significant mediating role in the relationships between Carbon Accounting, Digital Transformation, Energy Efficiency, and Sustainability Performance. These results indicate that sustainability-related capabilities do not only affect sustainability performance directly but also operate indirectly through improving the quality of financial decision-making processes.

Finally, the moderation hypotheses (H12–H14) were accepted, confirming that Global Uncertainty significantly moderates the relationships between Carbon Accounting, Digital Transformation, Energy Efficiency, and Financial Decision-Making Quality. The negative

interaction effects indicate that higher levels of global uncertainty weaken the positive contributions of carbon accounting, digital transformation, and energy efficiency to financial decision-making quality.

Overall, the hypothesis testing results provide strong support for the proposed research model. The findings highlight that sustainability-oriented practices and digital capabilities enhance financial decision quality and sustainability performance, while global uncertainty acts as an external constraint that reduces the effectiveness of these internal capabilities.

5. Discussion

The findings of this study provide strong empirical support for the strategic role of Carbon Accounting (CA) in enhancing Financial Decision-Making Quality (FDMQ) and Sustainability Performance (SP). As shown in Table 6, Carbon Accounting has a positive and statistically significant effect on Financial Decision-Making Quality ($\beta = 0.0185$, $p = 0.021$), while Table 7 confirms its positive and significant effect on Sustainability Performance ($\beta = 0.0168$, $p = 0.034$). These results support Hypotheses H1 and H2 and indicate that carbon-related information represents an important strategic resource that improves managerial financial decisions and contributes to sustainability-oriented outcomes. From the perspective of Dynamic Capabilities Theory, these findings confirm that carbon accounting functions as a sensing capability that enables firms to identify environmental risks, measure emissions-related costs, and recognize operational inefficiencies. According to the dynamic capabilities perspective, competitive advantage does not result merely from possessing resources but from the ability to identify environmental changes and transform information into strategic actions [52,53]. Therefore, carbon accounting provides firms with environmental intelligence that can be incorporated into investment evaluation, cost management, risk assessment, and sustainability planning. The positive relationship between carbon accounting and financial decision-making quality is consistent with previous studies emphasizing that carbon disclosure enhances the informational value of accounting systems and improves decision usefulness [5,19]. In particular, ref. [6] argues that carbon accounting improves the accuracy of environmental measurement and reporting, while refs. [18,21] highlight that comprehensive emissions measurement, including Scope 1–3 emissions, strengthens information reliability and supports strategic decision-making. The current findings extend these arguments by demonstrating empirically that carbon accounting not only improves transparency but also contributes directly to the internal quality of financial decisions within high-emission industries. Furthermore, the positive relationship between Carbon Accounting and Sustainability Performance supports previous research indicating that carbon measurement and disclosure practices improve environmental management, regulatory compliance, and stakeholder confidence [18,19]. However, unlike studies that primarily view carbon accounting as a reporting mechanism, the present findings demonstrate its broader strategic role by showing that carbon information becomes more valuable when integrated into organizational decision systems. This result addresses an important limitation identified in the previous literature, as earlier studies have often examined carbon accounting from a narrow measurement and disclosure perspective [6,14–16], while paying limited attention to how carbon information is transformed into organizational capabilities. The current findings suggest that carbon accounting creates value not simply through disclosure but through its ability to enhance managerial understanding of environmental costs and risks, thereby improving both financial decisions and sustainability outcomes.

Study Limitations and Future Research

Despite the significant findings of this study, several limitations should be acknowledged. First, although the panel dataset includes 59 firm-year observations, this sample represents the complete population of industrial firms listed on the Palestine Exchange (PEX) that met the study's selection criteria. Therefore, the findings provide meaningful insights within the Palestinian industrial context; however, their generalizability to other markets with different institutional, economic, and geopolitical conditions should be approached with caution.

Second, while the study employs a structured content analysis approach to transform corporate disclosures into measurable constructs, future research could enhance the depth of understanding by incorporating primary data sources, such as surveys and interviews with financial managers and executives, to capture internal decision-making mechanisms and managerial responses under uncertainty conditions.

Third, the study period (2020–2025) coincides with major global and regional disruptions, including the COVID-19 pandemic and geopolitical instability. Although year-fixed effects were incorporated into the panel regression models to control for common time-specific shocks, these exceptional conditions may influence firms' strategic behaviors and financial decisions. Future studies could extend the observation period to include more stable economic conditions and examine whether the identified relationships remain consistent over different economic cycles.

Finally, despite the robustness checks conducted to reduce potential endogeneity concerns, future research may employ larger datasets and advanced causal identification approaches, such as instrumental variable techniques or dynamic panel models, when sufficient data availability permits. This would provide further evidence regarding the causal mechanisms linking sustainability capabilities, digital transformation, and financial decision-making quality.

6. Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. High-emission industrial firms should strengthen the adoption of comprehensive carbon accounting systems that integrate emissions measurement, reporting, and environmental cost information into financial decision-making processes to improve both financial decision quality and sustainability performance.
2. Organizations should accelerate digital transformation initiatives by investing in advanced technologies such as artificial intelligence, the Internet of Things (IoT), cloud computing, and integrated enterprise resource planning (ERP) systems to enhance data quality, analytical capabilities, and sustainability-oriented financial decision-making.
3. Industrial firms should prioritize energy efficiency programs through investments in energy-saving technologies, process optimization, and continuous monitoring systems, as these initiatives contribute to operational efficiency, cost reduction, and long-term sustainability performance.
4. Managers should incorporate carbon-related information, environmental risks, and sustainability indicators into strategic financial planning and investment evaluation to support evidence-based decision-making under changing environmental conditions.
5. Policymakers and regulatory authorities should establish standardized carbon accounting guidelines and reporting frameworks to improve the consistency, comparability, and reliability of environmental disclosures across high-emission industries.
6. Governments should encourage the digitalization of environmental and accounting systems by providing financial incentives, technical support, and regulatory frameworks that facilitate the adoption of digital technologies in industrial organizations.

7. Industrial companies should develop integrated risk management systems capable of monitoring and responding to global uncertainty, including economic volatility, climate-related risks, and regulatory changes, in order to reduce their adverse effects on financial decision-making quality.
8. Organizations should strengthen internal capabilities by providing continuous training programs that enhance employees' competencies in carbon accounting, digital technologies, sustainability management, and financial analytics.
9. Decision-makers should adopt an integrated management approach that combines carbon accounting, digital transformation, and energy efficiency as complementary strategic capabilities rather than treating them as isolated initiatives, thereby maximizing their contribution to sustainable organizational performance.
10. Future research should extend the proposed framework by examining additional mediating and moderating variables, such as organizational resilience, environmental governance, innovation capability, institutional quality, or green finance, and by applying the model to different countries, industries, and longitudinal settings to improve the generalizability of the findings.
11. The Palestine Exchange (PEX) and policymakers should establish crisis-sensitive ESG disclosure frameworks that enable listed companies to report sustainability performance, climate risks, operational disruptions, and recovery strategies during periods of conflict and economic instability. Such frameworks should balance transparency requirements with the practical challenges faced by firms operating under emergency conditions, thereby supporting informed investment decisions, strengthening market confidence, and enhancing corporate resilience.

7. Conclusions

This study concludes that an integrated empirical framework combining Carbon Accounting (CA), Digital Transformation (DT), Energy Efficiency (EE), Global Uncertainty (GU), Financial Decision-Making Quality (FDMQ), and Sustainability Performance (SP) provides a comprehensive explanation of how strategic organizational capabilities contribute to sustainable performance in high-emission industries. Drawing on Dynamic Capabilities Theory, the findings demonstrate that sustainability-related capabilities should not be viewed as isolated organizational practices but rather as complementary and interdependent mechanisms whose effectiveness depends on firms' ability to transform environmental and operational information into high-quality financial decisions under changing external conditions.

First, the study confirms that Carbon Accounting significantly enhances both Financial Decision-Making Quality (H1 supported) and Sustainability Performance (H2 supported). The findings indicate that systematic measurement, reporting, and management of carbon emissions improve the availability and reliability of environmental information, enabling firms to better evaluate environmental costs, regulatory risks, and strategic investment opportunities. This supports the argument that carbon accounting functions not only as a compliance mechanism but also as a strategic managerial capability that strengthens both financial and sustainability outcomes.

Second, Digital Transformation emerges as one of the strongest positive determinants of Financial Decision-Making Quality (H3 supported) and Sustainability Performance (H4 supported). The results suggest that investments in digital technologies improve data integration, analytical capabilities, and managerial decision-support systems, allowing organizations to process financial and environmental information more efficiently. These findings reinforce the Dynamic Capabilities perspective by demonstrating that digital transformation represents a "seizing capability" through which firms con-

vert environmental and operational data into effective strategic decisions and sustainable organizational performance.

Third, Energy Efficiency is found to have a positive and statistically significant influence on both Financial Decision-Making Quality (H7 supported) and Sustainability Performance (H8 supported). The results indicate that efficient energy utilization improves operational efficiency, strengthens cost management, and provides valuable performance information that enhances managerial decision quality while simultaneously supporting environmental sustainability objectives. This finding confirms that energy efficiency represents an important organizational capability that simultaneously generates operational and strategic benefits.

Fourth, the study demonstrates that Global Uncertainty exerts a significant negative influence on both Financial Decision-Making Quality (H5 supported) and Sustainability Performance (H6 supported). The findings indicate that increasing uncertainty associated with economic volatility, regulatory changes, and external environmental pressures reduces firms' ability to make effective financial decisions and achieve sustainability objectives. This confirms that uncertainty acts as an external constraint limiting the effectiveness of organizational capabilities, consistent with the assumptions of Dynamic Capabilities Theory regarding the challenges posed by rapidly changing environments.

Fifth, the study provides strong empirical evidence for the mediating role of Financial Decision-Making Quality in explaining how Carbon Accounting, Digital Transformation, and Energy Efficiency contribute to Sustainability Performance (H9–H11 supported). Rather than influencing sustainability only through direct pathways, these strategic capabilities improve sustainability performance by enhancing the quality of financial decisions related to investment, resource allocation, risk management, and long-term planning. This finding extends previous research by identifying the organizational mechanism through which sustainability-oriented capabilities are translated into measurable sustainability outcomes.

Sixth, the findings confirm that Global Uncertainty negatively moderates the relationships between Carbon Accounting, Digital Transformation, and Energy Efficiency and Financial Decision-Making Quality (H12–H14 supported). The significant negative interaction effects indicate that although these strategic capabilities improve decision quality under normal conditions, their effectiveness declines as external uncertainty increases. This suggests that firms require stronger adaptive capabilities and organizational resilience to maintain the benefits of sustainability initiatives during periods of heightened environmental and economic uncertainty.

Overall, the study concludes that sustainability performance in high-emission industries is achieved through an integrated system in which Carbon Accounting provides environmental intelligence, Digital Transformation enables information integration and strategic analysis, Energy Efficiency improves operational effectiveness, and Financial Decision-Making Quality converts these organizational capabilities into sustainable performance outcomes. At the same time, Global Uncertainty represents an important contextual condition that weakens these positive relationships and emphasizes the need for continuous organizational adaptation.

Finally, this study contributes to the sustainability, accounting, and strategic management literature by empirically validating an integrated Dynamic Capabilities framework that simultaneously examines direct, mediating, and moderating relationships among environmental, technological, operational, and contextual factors. By demonstrating that Financial Decision-Making Quality represents the central mechanism linking organizational capabilities to Sustainability Performance, while Global Uncertainty shapes the strength of these relationships, the study provides a more comprehensive explanation of

how high-emission industrial firms can achieve sustainable competitive performance under increasingly uncertain business environments.

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Appendix A

Table A1. Scoring Rubric for Content Analysis.

Variable	Indicators	Measurement Criteria	Weighting Method	Data Source
Digital Transformation (DT)	ERP adoption, process automation, AI investment, digital strategy	1 = No mention; 2 = General mention; 3 = Strategic plans announced; 4 = Full implementation and documented investment	Equal weights assigned to all indicators; composite score calculated as the average of indicators	Annual reports, corporate disclosures
Carbon Accounting (CA)	Emission measurement, sustainability reporting, climate disclosures	1 = No disclosure; 2 = General environmental statement; 3 = Partial measurement/disclosure; 4 = Comprehensive and verified reporting	Equal weights assigned to disclosure dimensions	Annual reports, sustainability reports
Energy Efficiency (EE)	Energy-saving initiatives, reduction targets, green technology integration	1 = No mention; 2 = General awareness; 3 = Specific efficiency projects; 4 = Audited/certified performance	Equal weights assigned to indicators	Annual reports, environmental disclosures
Financial Decision-Making Quality (FDMQ)	Strategic evaluation processes, analytical tools, financial information accuracy	1 = Basic decisions; 2 = Limited reporting use; 3 = Systematic analytical process; 4 = Strategic integration of analytics	Equal weights assigned to dimensions	Financial reports and management disclosures
Sustainability Performance (SP)	Environmental, social, and economic performance indicators	1 = Limited disclosure; 2 = Basic sustainability information; 3 = Structured sustainability practices; 4 = Comprehensive sustainability performance	Equal weights assigned to dimensions	Sustainability reports and annual reports
Global Uncertainty (GU)	Global uncertainty index	Annual index value	External standardized measure	World Uncertainty Index (WUI)

Table A2. List of Symbols and Abbreviations.

Symbol/Abbreviation	Definition
FDMQ	Financial Decision-Making Quality
CA	Carbon Accounting
DT	Digital Transformation
EE	Energy Efficiency
GU	Global Uncertainty
SP	Sustainability Performance
Y	Value of the dependent variable
i	Individual industrial company within the sample
t	Observation year
N	Number of companies included in the sample
μ_i	Firm-specific effects
ε_{it}	Error term

Table A3. Summary of Model Equations.

Equation No.	Equation Description	Equation
Equation (A1)	Panel data structure	$Y_{it}, i = 1, 2, \dots, N \text{ And } t = 2020, 2021, \dots, 2025.$
Equation (A2)	Fixed Effects Model for Financial Decision-Making Quality (Direct Effects Model)	$FDMQ_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 SIZE_{it} + \beta_6 LEV_{it} + \mu_i + \varepsilon_{it}.$
Equation (A3)	Moderation Model of Global Uncertainty on Financial Decision-Making Quality	$FDMQ_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 (CA \times GU)_{it} + \beta_6 (DT \times GU)_{it} + \beta_7 (EE \times GU)_{it} + \beta_8 SIZE_{it} + \beta_9 LEV_{it} + \mu_i + \varepsilon_{it}.$
Equation (A4)	Sustainability Performance Model	$SP_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 FDMQ_{it} + \beta_6 SIZE_{it} + \beta_7 LEV_{it} + \mu_i + \varepsilon_{it}.$
Equation (A5)	Calculation of the Indirect Effect	Indirect Effect = $(X \rightarrow FDMQ) \times (FDMQ \rightarrow SP).$
Equation (A6)	Fixed Effects Model for Financial Decision-Making Quality (Direct Effects Model)	$FDMQ_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 SIZE_{it} + \beta_6 LEV_{it} + \mu_i + \varepsilon_{it}.$
Equation (A7)	Sustainability Performance Model	$SP_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 FDMQ_{it} + \beta_6 SIZE_{it} + \beta_7 LEV_{it} + \mu_i + \varepsilon_{it}.$
Equation (A8)	Moderation Model of Global Uncertainty on Financial Decision-Making Quality	$FDMQ_{it} = \beta_0 + \beta_1 CA_{it} + \beta_2 DT_{it} + \beta_3 EE_{it} + \beta_4 GU_{it} + \beta_5 (CA \times GU)_{it} + \beta_6 (DT \times GU)_{it} + \beta_7 (EE \times GU)_{it} + \beta_8 SIZE_{it} + \beta_9 LEV_{it} + \mu_i + \varepsilon_{it}.$

Note: All equations are numbered sequentially according to their appearance in the manuscript to facilitate cross-referencing throughout the text.

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