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PREDICTIVE OPTIMIZATION AS A STRATEGIC CAPABILITY FOR SUSTAINABLE COMPETITIVENESS

OTIMIZAÇÃO PREDITIVA COMO CAPACIDADE ESTRATÉGICA PARA COMPETITIVIDADE SUSTENTÁVEL

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ABSTRACT

Digital transformation and ESG agendas have advanced in parallel and often fragmented ways within organizations. This article argues that sustainable competitiveness does not emerge from isolated technology adoption, but from the organizational capability to use predictive intelligence to integrate operational efficiency, sustainability, and strategic decision-making. Drawing on a theoretical-conceptual approach with an integrative literature review (2010–2024), predictive optimization is proposed as a VRIN strategic capability grounded in the Resource-Based View (RBV) and Dynamic Capabilities Theory. The central distinction is that isolated digital technologies are commoditizable; competitive advantage emerges when organizations build integrated analytical routines, learn continuously, and develop adaptive capability oriented toward ESG. Applications across the three ESG pillars — a 15–25% reduction in energy consumption, a 30–50% decline in workplace accidents, and early detection of up to 95% of financial fraud — demonstrate how predictive intelligence converts operational data into hard-to-replicate competitive advantage.
Keywords: Predictive Optimization; Sustainable Competitiveness; Dynamic Capabilities; RBV; ESG; Strategic Management.

RESUMO

A transformação digital e as agendas ESG têm avançado de forma paralela e, muitas vezes, fragmentada nas organizações. Este artigo argumenta que a competitividade sustentável não decorre da adoção isolada de tecnologias, mas sim da capacidade organizacional de utilizar a inteligência preditiva para integrar eficiência operacional, sustentabilidade e tomada de decisão estratégica. Com base em uma abordagem teórico-conceitual e em uma revisão integrativa da literatura (2010–2024), propõe-se a

otimização preditiva como uma capacidade estratégica VRIN, fundamentada na Visão Baseada em Recursos (RBV) e na Teoria das Capacidades Dinâmicas. A distinção central reside no fato de que tecnologias digitais isoladas são passíveis de comoditização; a vantagem competitiva surge quando as organizações estabelecem rotinas analíticas integradas, aprendem continuamente e desenvolvem uma capacidade adaptativa orientada para o ESG. Aplicações nos três pilares do ESG — redução de 15% a 25% no consumo de energia, queda de 30% a 50% nos acidentes de trabalho e detecção precoce de até 95% das fraudes financeiras — demonstram como a inteligência preditiva converte dados operacionais em uma vantagem competitiva de difícil replicação.
Palavras-chave: Otimização Preditiva; Competitividade Sustentável; Capacidades Dinâmicas; RBV; ESG; Gestão Estratégica.

1. INTRODUCTION

Digital transformation has become a structural force in contemporary organizations, reconfiguring business models, production chains, and sources of competitive advantage (Schwab, 2016; Kagermann et al., 2013). Technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), advanced analytics, and intelligent automation are redefining production logic and accelerating organizational responsiveness.

In parallel, ESG (Environmental, Social, and Governance) principles have become consolidated as a global reference for corporate sustainability. Robust empirical evidence indicates that companies with stronger ESG performance tend to show superior financial results, lower risk exposure, and greater stakeholder trust (Friede et al., 2015; Eccles et al., 2014; Whelan et al., 2021).

Despite the growing relevance of both agendas, their integration remains fragmented within organizations. Companies digitize operations and adopt ESG practices, but rarely treat them as mutually reinforcing forces — underutilizing the competitive potential that emerges precisely from combining analytical intelligence with socio-environmental responsibility. This gap is particularly critical for the field devoted to integrating strategy, technology, and sustainability (Tortorella; Fettermann, 2018; Morioka; Carvalho, 2017).

The central problem this article addresses can be formulated as follows: if digital technologies are increasingly accessible and ESG practices increasingly widespread, why do so few organizations manage to convert them into sustainable competitive advantage? The answer, it is argued here, lies in the absence of an integrating organizational capability — and predictive optimization is proposed as that mechanism.

The research question guiding this study is: how can predictive optimization act as a strategic capability to promote sustainable competitiveness? The objective is to analyze predictive optimization as a strategic mechanism capable of integrating digital transformation, ESG practices, and sustainable competitiveness, theoretically grounded in the Resource-Based View (RBV), Dynamic Capabilities (Teece et al., 1997), and the Triple Bottom Line (Elkington, 1997).

Methodologically, this study adopts a theoretical-conceptual approach grounded in an integrative literature review (Torraco, 2005; Snyder, 2019), following the principles for constructing conceptual articles proposed by Jaakkola (2020), which enables the synthesis and theoretical articulation of distinct bodies of knowledge — digital transformation, ESG, and strategic theory — into an original integrative model.

The article is organized into six sections: following this introduction, the theoretical foundation is presented (Section 2), followed by the conceptualization and operationalization of predictive optimization as a strategic capability (Section 3), the integrative conceptual model (Section 4), the discussion (Section 5), and the conclusions and future research agenda (Section 6).

2. THEORETICAL FOUNDATION

2.1. Digital Transformation And Competitiveness

Digital transformation represents a structural shift that redefines how economic and social value is created (Brynjolfsson; McAfee, 2014). Industry 4.0 inaugurates a new production logic based on cyber-physical systems that integrate physical and digital environments, enabling real-time optimization, self-configuration, and adaptive control capabilities (Kagermann et al., 2013). Technologies such as AI, IoT, digital twins, advanced analytics, and smart manufacturing reconfigure processes and business models, generating new sources of competitive advantage (Kane et al., 2019).

However, isolated technology adoption does not guarantee sustainable competitive advantage. Carvalho et al. (2021) highlight relevant conceptual challenges regarding the operationalization of digital transformation across different organizational contexts. In the Brazilian context, Tortorella and Fettermann (2018) find that the transition to advanced manufacturing occurs heterogeneously, with significant differences in digital maturity. This diagnosis reinforces the need for a perspective that goes beyond technology adoption and recognizes organizational capabilities as the true locus of competitive advantage.

2.2. ESG And Sustainable Competitiveness

ESG performance correlates positively with financial results in approximately 90% of the empirical studies analyzed by Friede et al. (2015), a meta-analysis spanning more than 2,000 investigations. Whelan et al. (2021) reinforce this evidence by synthesizing more than 1,000 studies published between 2015 and 2020. Porter and van der Linde (1995) demonstrate that stringent environmental policies can generate efficiency gains that exceed their costs — the so-called Porter Hypothesis — while the Triple Bottom Line (Elkington, 1997) consolidates the integrated assessment of performance across environmental, social, and economic dimensions.

Hart and Milstein (2003) advance the argument that socio-environmental challenges can drive strategies for creating value simultaneously across all three dimensions. In the Brazilian context, Morioka and Carvalho (2017) identify difficulties in translating sustainability into measurable organizational practices — evidence that ESG, by itself, does not automatically translate into competitiveness. The missing link, it is argued here, is precisely the predictive capability that makes ESG management proactive, continuous, and strategically oriented.

2.3. Resource-Based View And Dynamic Capabilities: The Theoretical Engine Of The Article

This section constitutes the theoretical core of the article. Its purpose is not merely to review Barney and Teece, but to build the central argument underpinning predictive optimization as a higher-order strategic capability — rather than as a simple technological tool.

2.3.1. Resource-Based View: Not All Technology Is Strategic

The Resource-Based View (Barney, 1991) posits that sustainable competitive advantage emerges from resources that simultaneously satisfy four criteria: value, rarity, inimitability, and non-substitutability (VRIN). Resource heterogeneity among firms explains why organizations within the same industry exhibit persistently different performance levels — an argument incompatible with the notion that adopting the same technologies would generate the same competitive outcomes.

This point is crucial for the present article: isolated digital technologies — access to AI platforms, IoT sensors, or analytics software — tend not to satisfy the VRIN criteria, precisely because they are widely available on the technology market. A production line equipped with IoT can be replicated by any competitor with sufficient capital. A machine learning algorithm can be licensed. Compliance software can be purchased.

The competitive differential, therefore, does not lie in the possession of these technologies, but in the organizational capability to integrate them, combine them with proprietary data, embed them in unique decision-making routines, and develop accumulated analytical learning over time. This capability, built in a path-dependent manner — dependent on historical trajectory, organizational culture, and cumulative investment — is causally ambiguous and socially complex. It is, by definition, VRIN.

2.3.2. Dynamic Capabilities: Predictive Optimization Operationalizes The Strategic Cycle

Dynamic Capabilities (Teece et al., 1997; Teece, 2007) complement the RBV by answering the question it leaves open: how do organizations create, maintain, and renew competitive advantage in rapidly changing environments? The answer lies in the ability to integrate, build, and reconfigure internal and external competencies — which Teece (2007) operationalizes through the sensing–seizing–transforming cycle.

Sensing refers to the capability to identify and assess opportunities and threats in the environment; seizing refers to mobilizing resources to capture those opportunities; transforming corresponds to the continuous reconfiguration of assets, processes, and organizational structures in response to detected changes.

Predictive optimization operationalizes this cycle directly and measurably within the ESG context, as summarized in Table 1.

Table 1. Dynamic Capabilities and the Role of Predictive Optimization in the ESG Context

Dynamic Capability	Role of Predictive Optimization	Applied Example
Sensing	Detecting ESG patterns in operational, climate, and financial data; identifying risks before they materialize	Forecasting energy consumption, accident risk, compliance anomalies
Seizing	Supporting and accelerating strategic decisions based on predictive scenarios and prescriptive analysis	Logistics route optimization, resource allocation, automated compliance

Transformin g	Continuously adapting operations, processes, and organizational routines based on accumulated analytical learning	Reconfiguration of production lines, updating predictive models, adjusting ESG targets

Source: *Prepared by the authors based on Teece (2007).*

Table 1 shows that predictive optimization does not merely support operational decisions — it institutionalizes the sensing–seizing–transforming cycle as a continuous organizational routine. When integrated into the ESG context, this routine allows the organization to anticipate environmental risks before they materialize, reconfigure operations in response to consumption or safety patterns, and learn adaptively from each data cycle. This cumulative process of analytical learning is precisely what makes predictive capability difficult for competitors to replicate — even when they have access to the same technologies.

2.3.3. Synthesis: Predictive Optimization as a Strategic Organizational Capability

The central conceptual distinction of this article can now be stated precisely: predictive optimization is not automation, not analytics, and not applied AI. It is a strategic organizational capability that integrates knowledge, transforms data into action, coordinates decisions across the three ESG pillars, and generates continuous organizational learning.

Technologies can be copied. Organizational analytical capabilities, built over time on proprietary data, unique routines, and an evidence-based decision-making culture, cannot. This is the central argument of the RBV — and it is exactly what positions predictive optimization as a source of sustainable competitive advantage.

The theoretical consequence of this distinction is immediate: the correct analytical vocabulary is not 'technology adoption,' but 'building organizational capability grounded in predictive intelligence.' This shift in framing elevates the argument from the operational to the strategic plane — and it is what gives this article its distinctive contribution relative to literature that treats digital transformation and ESG as technical or compliance agendas.

3. PREDICTIVE OPTIMIZATION AS A STRATEGIC CAPABILITY

3.1. Conceptualization And Operational Definition

Based on the theoretical foundation presented, predictive optimization is defined in this article as the organizational capability to anticipate future events — risks, opportunities, or performance deviations — related to operational and ESG dimensions, and to prescribe optimal actions that simultaneously maximize efficiency, sustainability, and competitiveness outcomes, in an integrated and continuous manner.

This definition differs from narrower technological approaches by incorporating three interdependent components: (i) Forecasting — statistical and machine learning models that anticipate future outcomes from historical patterns and contextual variables; (ii) Prescriptive Analytics — optimization algorithms that identify the optimal decision among multiple possible scenarios; and (iii) Intelligent Automation — systems capable of executing recommendations with minimal human intervention, within predefined governance parameters.

In advanced stages of organizational maturity, these components converge into prescriptive, autonomous systems — configuring what Teece (2007) terms a higher-order dynamic capability: an organizational routine that is difficult to replicate, embedded in proprietary data, unique processes, and accumulated learning.

3.2. Enabling Technological Components

The operationalization of predictive optimization relies on a convergent technological ecosystem. It is important to note that these components are necessary but not sufficient conditions — the strategic differential emerges from their integration and from the organizational capability to coordinate them:

- Machine Learning and Deep Learning — models that learn patterns from large volumes of operational, climate, financial, and social data, generating forecasts with increasing accuracy;

- Internet of Things (IoT) and Edge Analytics — distributed sensors that capture real-time data directly from assets and production processes, feeding predictive models;

- Digital Twins — digital replicas of assets, processes, or systems that allow scenarios to be simulated and decisions tested before physical implementation;

- Optimization Algorithms — mathematical and heuristic methods that identify the optimal solution among multiple alternatives, simultaneously considering operational constraints and ESG objectives;

- Autonomous Systems and Intelligent RPA — agents capable of executing actions autonomously based on the prescriptions of analytical models, reducing the latency between decision and action.

Integrating these components is not automatic — it requires organizational routines, data absorption capability, and deliberate strategic alignment. It is this integration, not the individual components, that constitutes the strategic capability.

3.3. Strategic Applications Across The ESG Pillars

Predictive optimization applies transversally across the three ESG pillars, generating measurable competitive impacts. Table 2 details representative applications and their estimated benefits.

Table 2. Predictive Optimization Applications by ESG Pillar and Competitive Impacts

ESG Pillar	Representative Application	Estimated Competitive Benefits
Environmental (E)	Forecasting energy consumption via machine learning based on climate and operational variables	15–25% reduction in energy consumption and 10–20% in CO_2 emissions; savings from reduced reliance on polluting sources
Social (S)	Predicting accident risk through algorithms that analyze fatigue, maintenance history, and operational conditions	30–50% reduction in accident rates; 15–25% increase in employee satisfaction; 20–35% reduction in turnover
Governance (G)	Detecting financial anomalies via unsupervised	Early detection of 85–95% of fraud and irregularities;

	models (Isolation Forests, Autoencoders)	prevention of financial losses; strengthened governance

Note: *Values are illustrative estimates subject to variation according to industry and digital maturity (Dhiman et al., 2024). Source: Adapted by the authors.*

The most relevant aspect of Table 2, from a strategic standpoint, is the multiplier effect: the same data infrastructure that reduces energy consumption also feeds occupational safety monitoring and financial anomaly detection. This represents multidimensional value creation at decreasing marginal cost — one of the defining characteristics of genuinely VRIN strategic capabilities.

3.4. Sustainable Competitiveness as An Outcome

Sustainable competitiveness — understood as the organizational capability to generate and sustain competitive advantage over time, simultaneously considering economic, environmental, and social dimensions (Elkington, 1997; Porter; Kramer, 2011) — is the central outcome of predictive optimization when applied to the ESG context. Table 3 synthesizes the links between specific predictive capabilities and their competitive impacts.

Table 3. Predictive Capabilities and Competitive Impacts on Strategic Management

Predictive Capability	Competitive Impact	ESG Pillar
Energy forecasting (ML)	Reduced operational costs	Environmental (E)
Real-time ESG analytics	Faster strategic decisions	Governance (G)

Operational AI and predictive maintenance	Increased productivity and uptime	Environmenta l (E)
Algorithm-based accident prevention	Reduced turnover and labor liabilities	Social (S)
Automated intelligent compliance	Legitimacy and preferential access to capital	Governance (G)
Financial anomaly detection	Reputational protection and reduced fraud	Governance (G)

Source: *Prepared by the authors.*

In summary, predictive optimization generates six simultaneous vectors of competitiveness: (i) cost reduction through energy efficiency and predictive maintenance; (ii) increased productivity through minimizing failures and downtime; (iii) improved organizational agility by shortening the data–decision–action cycle; (iv) strengthened legitimacy through transparency and automated compliance; (v) reduced operational, regulatory, and reputational risks; and (vi) enhanced resilience against external shocks. These vectors configure a sustainable competitive advantage grounded in analytical capability — not in the possession of digital assets.

4. CONCEPTUAL MODEL

The proposed conceptual model articulates the article's central causal chain, illustrating how predictive optimization acts as an integrating mechanism among digital transformation, ESG, and sustainable competitiveness.

Figure 1. *Conceptual model: predictive optimization as an integrating mechanism of sustainable competitiveness. Source:*

Prepared by the authors.

Digital Transformation → Analytical Technologies

↓

Predictive Optimization (sensing · seizing · transforming)

↓

ESG Integration (Environmental · Social · Governance)

↓

Efficiency + Responsiveness + Legitimacy

↓

SUSTAINABLE COMPETITIVENESS

The model's logic is sequential and cumulative. Digital transformation provides the enabling technological context. Predictive optimization — anchored in the sensing–seizing–transforming cycle — is the mechanism that converts analytical capabilities into actionable strategic intelligence, applied transversally across the three ESG pillars. The outcome manifests in three interdependent competitive vectors: efficiency, responsiveness, and legitimacy. The combination of these vectors, sustained by VRIN capabilities that are difficult to replicate, configures sustainable competitiveness as a long-term organizational outcome.

5. DISCUSSION

The results presented support the central argument: sustainable competitiveness does not emerge from digitalization or ESG in isolation, but from the organizational capability to transform data into strategic intelligence oriented toward sustainability. The theoretical depth of Section 2.3 is what gives the argument its distinction relative to existing literature.

The most relevant point of the discussion is the break with technological determinism. The Industry 4.0 literature tends to treat technology adoption as a sufficient condition for competitive gains (Kagermann et al., 2013). This article inverts that logic: it is organizational analytical capabilities — not the technologies themselves — that generate sustainable competitive advantage. This reorientation engages directly with the RBV and aligns with Carvalho et al.'s (2021) critique of digital determinism.

From a Dynamic Capabilities perspective, predictive optimization represents an institutionalization of the sensing–seizing–transforming cycle as a continuous organizational routine. When integrated into the ESG context, this routine generates cumulative effects: with each data cycle, predictive models become more accurate, decision routines become more refined, and organizational learning deepens — creating growing barriers to imitation over time.

From a practical standpoint, the estimates in Table 2 show that predictive optimization generates simultaneous and mutually reinforcing returns. Reducing workplace accidents not only improves the social pillar but also reduces labor liabilities and improves organizational climate — which in turn increases productivity. This multiplier effect is invisible to traditional ESG reporting based on periodic disclosures, and only becomes measurable and manageable through continuous predictive capabilities.

In the Brazilian context, the relevance of the proposal is reinforced by the heterogeneity of digital maturity (Tortorella; Fettermann, 2018). SMEs can adopt incremental implementation strategies — prioritizing high-impact, low-entry-cost applications, such as forecasting energy consumption via models available on SaaS platforms — and progressively evolve toward more advanced stages of analytical autonomy.

Finally, legitimacy as a competitiveness vector deserves special attention. Organizations with digitally operationalized and real-time auditable ESG practices have an advantage in accessing ESG capital, attracting talent, and reaching markets that require socio-environmental traceability — an increasingly relevant dimension both in the domestic market and in the Luso-Brazilian context addressed by CIGELUBRA.

6. CONCLUSION

This article proposed predictive optimization as a strategic capability for promoting sustainable competitiveness. The central argument — that the competitive differential does not lie in the possession of digital technologies, but in the organizational capability to integrate them into ESG-oriented analytical routines — was grounded in the RBV, Dynamic Capabilities, and the Triple Bottom Line.

The study's theoretical contributions are threefold: (i) conceptualizing predictive optimization as a VRIN dynamic capability, rigorously distinguishing it from isolated technology adoption; (ii) proposing a conceptual model that articulates digital transformation, ESG, and sustainable competitiveness in a coherent causal chain, mediated by the sensing–seizing–transforming cycle; and (iii) demonstrating that the synergy between digitalization and ESG generates competitive impacts superior to isolated initiatives, through three vectors — efficiency, responsiveness, and legitimacy.

Practical contributions include a reference framework for managers on how to prioritize investments in ESG-oriented analytical capabilities, with an emphasis on high-impact applications adaptable to different levels of digital maturity.

As a main limitation, this study's theoretical-conceptual nature stands out, requiring empirical validation in real organizational contexts. As a future research agenda, it is recommended: (i) surveys with Brazilian industrial companies on ESG analytics adoption and its impacts on competitiveness; (ii) longitudinal case studies in technology-intensive sectors; (iii) development of digital maturity models for sustainable competitiveness; and (iv) comparative Brazil–Portugal studies, relevant to the Luso-Brazilian Strategic Management community.

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