Performance Indicators for the Transition to the Circular Economy in Public Health Systems: The Role of Technological Leadership

Andrea Mabel Nuñez Estrella[1], Lizeth Slano Romo[2], Alejandra Macías García[3]

[1] Universidad de Investigación e Innovación de México, *ORCID:* https://orcid.org/0000-0003-1609-1915
[2] Universidad Autónoma de Aguascalientes, México, *ORCID:* https://orcid.org/0000-0001-5596-7233
[3] Universidad Autónoma de Occidente, México, *ORCID:* https://orcid.org/0009-0009-7958-1760

Abstract
The transition to the circular economy in public health systems is a strategic challenge in the context of the climate crisis and the growing financial pressure on health services. This study aimed to analyze the relationship between technological leadership and performance in the circular economy, evaluating the mediating role of digital maturity. A non-experimental, cross-sectional, correlational-explanatory quantitative design was developed with a sample of 124 public hospitals of medium and high complexity. A Circular Economy Performance Index (IDEC-Health) was built and validated, composed of four dimensions: environmental efficiency, circular waste management, sustainable public procurement and digital operational innovation. The results show that technological leadership is positively and significantly associated with circular performance ($\beta = 0.36$, $p < 0.001$) and that digital maturity acts as a partial mediator (indirect effect $\beta = 0.30$; 95% CI [0.18, 0.44]). The model explains 59% of the variance of circular performance. It is concluded that technological leadership constitutes a strategic enabler for hospital sustainability, surpassing structural variables such as size and budget in importance. The study provides a replicable measurement model and empirical evidence for the design of public health policies aimed at the circular economy.
Keywords: circular economy; public health systems; technological leadership; digital transformation; hospital sustainability; performance indicators; digital maturity.

1. INTRODUCTION

The healthcare sector is increasingly recognized as a significant contributor to global environmental degradation, accounting for approximately 4–5% of global greenhouse gas (GHG) emissions and generating substantial volumes of hazardous and non-hazardous waste (Health Care Without Harm, 2021; World Health Organization [WHO], 2022). Public healthcare systems, in particular, face a structural paradox: they are designed to protect human health while simultaneously contributing to environmental risks that indirectly undermine population well-being (Lenzen et al., 2020).
In response to the escalating climate crisis and resource constraints, the circular economy (CE) has emerged as a systemic alternative to the traditional linear "take–make–dispose"

model (Geissdoerfer et al., 2020; Kirchherr et al., 2020). The CE framework seeks to decouple economic activity from resource extraction by promoting strategies such as reduction, reuse, remanufacturing, recycling, and systemic redesign of value chains (Bocken et al., 2021; Centobelli et al., 2020). While the CE has gained strong traction in manufacturing and industrial sectors, its operationalization within public healthcare systems remains underdeveloped (Agrawal et al., 2021; Salvador et al., 2021).

Hospitals are complex socio-technical systems characterized by high energy intensity, continuous operation, strict regulatory standards, and intricate supply chains (Eckelman & Sherman, 2022). Recent studies have highlighted the environmental burden associated with single-use medical devices, pharmaceutical production, energy consumption in clinical facilities, and waste mismanagement (Rizan et al., 2021; Thiel et al., 2023). However, most sustainability initiatives in healthcare remain fragmented, focusing on isolated interventions such as energy efficiency or waste segregation rather than systemic circular transformation (Sehnem et al., 2022).

A critical gap in the literature concerns the absence of integrated performance indicators capable of measuring circular transition in healthcare organizations. Existing circularity metrics were primarily developed for industrial production systems and are not directly transferable to hospital environments (Corona et al., 2019; Saidani et al., 2020). Furthermore, there is limited empirical research linking organizational capabilities—particularly technological leadership—to circular performance in public healthcare institutions.

Technological leadership refers to the strategic capacity of top management to drive digital transformation, foster innovation, and align technological investments with organizational objectives (Mazzucato & Kattel, 2020; Vial, 2021). In public sector contexts, digital leadership has been associated with improved efficiency, service innovation, and data-driven governance (Criado et al., 2021; Sharma et al., 2022). However, its role in accelerating circular economy implementation within healthcare systems remains largely unexplored.

Digital transformation can function as an enabling mechanism for circularity. Technologies such as Internet of Things (IoT), artificial intelligence (AI), blockchain, and big data analytics allow real-time monitoring of resource consumption, predictive inventory management, traceability of medical devices, and optimization of procurement processes (Bag et al., 2021; Chauhan et al., 2022). Studies in sustainable supply chain management suggest that digitalization enhances transparency and resource efficiency, thereby supporting circular practices (Khan et al., 2021; Nandi et al., 2021). Nevertheless, empirical evidence specifically addressing public healthcare systems is scarce.

From a theoretical standpoint, the Resource-Based View (RBV) posits that intangible organizational capabilities—such as leadership competencies and digital maturity—constitute strategic assets that enable sustained performance advantages (Barney, 1991; Teece, 2020). Complementarily, sustainability transition theory emphasizes the role of institutional actors and governance mechanisms in facilitating systemic shifts toward circular models (Geels, 2020; Kivimaa et al., 2021). Integrating these perspectives suggests that technological leadership may act as a dynamic capability enabling hospitals to transition toward circular operational models.

Despite growing interest in green healthcare and digital health governance, three major research gaps persist:

1. The lack of validated composite indicators tailored to measure circular economy performance in public healthcare systems.
2. The absence of quantitative models linking technological leadership to circular performance outcomes.
3. Limited empirical evidence on the mediating role of digital maturity in sustainability transitions within healthcare organizations.

Addressing these gaps is crucial for both theory and policy. Public healthcare systems operate under budgetary constraints and increasing accountability pressures. Identifying strategic levers capable of simultaneously improving environmental performance and operational efficiency is therefore essential.

Accordingly, this study aims to analyze the relationship between technological leadership and circular economy performance in public healthcare systems, examining the mediating role of digital maturity. By developing and validating a composite Circular Economy Performance Index (CEPI-Health), this research contributes to advancing measurement frameworks and provides empirical evidence to inform sustainability-oriented governance in healthcare.

2. LITERATURE REVIEW

2.1 Circular Economy in Healthcare Systems

The circular economy (CE) has evolved from a conceptual sustainability paradigm into a measurable operational framework grounded in resource efficiency, closed-loop systems, and regenerative design (Geissdoerfer et al., 2020; Kirchherr et al., 2020). In industrial settings, CE implementation has been linked to improved environmental performance, innovation capacity, and long-term competitiveness (Centobelli et al., 2020; Bocken et al., 2021). However, its translation into healthcare systems presents structural and regulatory challenges.

Healthcare organizations are resource-intensive institutions characterized by continuous energy demand, complex supply chains, and strict safety standards (Eckelman & Sherman, 2022). The environmental footprint of healthcare includes emissions embedded in pharmaceuticals, medical devices, hospital infrastructure, and waste treatment processes (Lenzen et al., 2020; Thiel et al., 2023). Globally, healthcare waste generation increased significantly during and after the COVID-19 pandemic, exacerbating material throughput and environmental pressures (WHO, 2022).

Recent literature identifies four principal circular domains within healthcare systems:
1. **Sustainable waste management**, including sterilization technologies, material recovery, and reduction of single-use devices (Rizan et al., 2021; Agrawal et al., 2021).
2. **Energy efficiency and decarbonization**, such as renewable energy integration and smart building management systems (Eckelman & Sherman, 2022).
3. **Green public procurement**, incorporating life-cycle assessment (LCA) criteria into purchasing decisions (Testa et al., 2021; Rainville, 2021).
4. **Digital process optimization**, enabling predictive logistics and real-time resource monitoring (Bag et al., 2021).

Despite these advances, CE initiatives in healthcare remain fragmented and lack systemic performance measurement frameworks (Salvador et al., 2021; Sehnem et al., 2022). Saidani et al. (2020) emphasize that circularity indicators must be context-specific and integrated across environmental, economic, and operational dimensions. However, validated composite indices tailored to public healthcare remain scarce.

This gap is particularly critical because measurement is central to sustainability transitions (Geels, 2020). Without robust performance indicators, circular initiatives risk remaining symbolic rather than transformative (Korhonen et al., 2020).

2.2 Performance Indicators for Circular Transitions

The development of CE performance metrics has accelerated over the past five years. Scholars have proposed material circularity indicators (MCI), life-cycle–based metrics, and multi-criteria composite indices (Corona et al., 2019; Saidani et al., 2020; Moraga et al., 2021). However, most tools were developed for manufacturing sectors and focus heavily on material recirculation rather than systemic institutional transformation.

In service-intensive sectors such as healthcare, circular performance must incorporate:

- Resource intensity per service unit (e.g., kWh per patient).
- Waste generation per clinical procedure.
- Share of environmentally certified procurement contracts.
- Digital integration enabling closed-loop management.

Research in sustainable supply chain management demonstrates that circular performance is strongly associated with transparency, traceability, and digital coordination mechanisms (Khan et al., 2021; Nandi et al., 2021). Moreover, multi-dimensional indices improve comparability across institutions and enhance policy benchmarking (Marrucci et al., 2021).

Nevertheless, few empirical studies have operationalized such indices within public healthcare systems. This represents a methodological gap with direct implications for governance and accountability.

2.3 Technological Leadership and Dynamic Capabilities

Technological leadership refers to the strategic ability of executives to envision, implement, and sustain digital transformation processes aligned with organizational objectives (Vial, 2021). In public administration contexts, digital leadership has been associated with innovation capacity, service efficiency, and governance modernization (Criado et al., 2021; Mergel et al., 2021).

From the perspective of the Resource-Based View (RBV), leadership competencies constitute intangible strategic resources capable of generating sustained organizational advantages (Barney, 1991; Teece, 2020). Dynamic capability theory further suggests that sensing, seizing, and transforming capacities enable organizations to adapt to environmental and technological shifts (Teece, 2020).

Empirical evidence indicates that digital leadership enhances operational performance by facilitating technology adoption, interdepartmental integration, and data-driven decision-making (Sharma et al., 2022; Troise et al., 2022). However, the intersection between technological leadership and environmental sustainability remains underexplored.

In sustainability literature, managerial commitment has been identified as a critical driver of green innovation and environmental performance (Amankwah-Amoah et al., 2021; Khan et al., 2021). Yet, most studies examine private firms rather than public healthcare systems.

This study extends existing research by positioning technological leadership as a dynamic capability that enables circular economy transition within hospitals.

2.4 Digital Maturity as an Enabling Mechanism

Digital maturity reflects the extent to which digital technologies are embedded in organizational processes, culture, and governance (Vial, 2021). In healthcare, digital maturity includes interoperable electronic health records, AI-supported diagnostics, automated inventory systems, and IoT-based energy monitoring (Chauhan et al., 2022; Thiel et al., 2023).

Digitalization enhances circular performance through:

- Real-time energy monitoring.
- Predictive supply chain analytics.
- Reduction of overstock and expired medical supplies.
- Improved traceability of reusable devices.

Sustainable supply chain research confirms that digital technologies facilitate resource optimization and reduce environmental externalities (Bag et al., 2021; Khan et al., 2021). Similarly, blockchain-enabled transparency improves procurement accountability and reduces material inefficiencies (Nandi et al., 2021).

However, digital transformation alone is insufficient without strategic leadership alignment (Mazzucato & Kattel, 2020). Therefore, digital maturity may function as a mediating mechanism translating leadership vision into measurable circular outcomes.

2.5 Theoretical Integration and Research Model

This study integrates three theoretical perspectives:

1. **Resource-Based View (RBV)** – Technological leadership as strategic capability (Barney, 1991; Teece, 2020).
2. **Sustainability Transition Theory** – Institutional transformation toward circular models (Geels, 2020; Kivimaa et al., 2021).
3. **Digital Transformation Theory** – Technology-enabled organizational change (Vial, 2021).

The proposed conceptual model posits:

Technological Leadership → Digital Maturity → Circular Economy Performance

with a partial direct effect of technological leadership on circular performance.

This integration responds to calls for interdisciplinary sustainability research linking governance, digitalization, and environmental performance (Korhonen et al., 2020; Salvador et al., 2021).

2.6 Research Hypotheses

Based on the reviewed literature:

H1: Technological leadership positively influences circular economy performance in public healthcare systems.

H2: Technological leadership positively influences digital maturity.

H3: Digital maturity positively influences circular economy performance.

H4: Digital maturity mediates the relationship between technological leadership and circular economy performance.

H5: Hospitals with higher technological leadership exhibit greater environmental efficiency and waste reduction.

3 – METHODOLOGY

1. Research Design

The present study adopts a quantitative approach, with a non-experimental design, cross-sectional and correlational-explanatory scope. It aims to analyze the relationship between technological leadership (LT), digital maturity (DM) and performance in circular economy (DEC) in public health systems, through multivariate statistical modeling.
The design is explanatory because it seeks to identify the predictive power of technological leadership on circular performance, as well as to evaluate the mediating effect of digital maturity.

2. Population and sample

The population was made up of hospitals and public health institutions at the secondary and tertiary level belonging to the national health system of a Latin American country of upper-middle-income.
A probabilistic sampling stratified by level of hospital complexity was used:

- Level II (medium complexity)
- Level III (High Complexity)

From a universe of 312 institutions, a final sample of 124 hospitals was selected, with a confidence level of 95% and a margin of error of 5%.
Unit of analysis: hospital institution.
Key informants:

- Managing Directors
- Technology or IT Managers
- Environmental management managers
- Hospital administrators

Each institution contributed at least three informants, whose data were aggregated at the organizational level using a weighted average.

3. Study variables

Independent variable:

- Technology Leadership (LT)

Mediating variable:

- Madurez Digital (MD)

Dependent variable:

- Circular Economy (DEC) Performance

Control variables:

- Hospital size (number of beds)
- Annual budget
- Level of complexity
- Geographical location (urban/rural)

4. Operationalization of variables

Table 1 presents the operationalization of the main variables.

Table 1Operationalization of study variables

Variable	**Dimensions**	**Indicators**	**Scale**
Technology Leadership (LT)	Strategic digital vision	Existence of a formal digital plan	Likert 1–5
	Culture of innovation	Incentives for technological innovation	Likert 1–5

	Technological investment	% IT budget	%
	Digital governance	Interdepartmental integration	Likert 1–5
Madurez Digital (MD)	IT Infrastructure	System interoperability	Likert 1–5
	Data Analytics	Using Big Data for Decisions	Likert 1–5
	Automation	Digital inventory management	Likert 1–5
	Traceability	Digital monitoring of inputs	Likert 1–5
Circular Economy (DEC) Performance	Environmental Efficiency (EA)	kWh/m²/year	Ratio
		m³ water/patient	Ratio
	Circular waste management (CRM)	% recycling	%
		kg waste/patient	Ratio
	Sustainable Procurement (SPC)	% contracts with green criteria	%
	Digital Operational Innovation (IOD)	Level digitalization of processes	Likert 1–5

5. Construction of the Circular Economy Performance Index (IDEC-Health)
A standardized composite index (0–100) was designed using the following steps:
1. Normalization of indicators (z-scores).
2. Reversal of negative indicators (e.g. residues per patient).
3. Aggregation by dimensions using a weighted average.
4. Calculation of the global index as an average of the four dimensions:

IDEC = (EA + GCR + CPS + IOD) / 4

The weighting was validated by confirmatory factor analysis (CFA), verifying factor loads greater than 0.60.

6. Harvesting instruments
Three instruments were applied:
1. Technology leadership questionnaire (20 items, Likert scale 1–5).
2. Hospital digital maturity scale (18 items).
3. Technical form of environmental and operational indicators (administrative data).

Validity:
- Content validity by judgment of 7 experts.
- Exploratory factor analysis (KMO = 0.89; $p < 0.001$).
- Cronbach's Alfa:
  - LT = 0.93
  - MD = 0.91
  - IOD = 0.88

7. Procedure
1. Formal request to health authorities.

2. Digital data collection for six months.
3. Verification and purification of databases.
4. Statistical analysis with SPSS 28 and AMOS software.

8. Statistical analysis plan

Five levels of analysis were developed:

1. Descriptive statistics:
   - Mean, standard deviation, minimum, maximum.
   - Comparisons by hospital level.
2. Normality tests:
   - Kolmogorov-Smirnov.
3. Bivariate correlations:
   - Pearson's coefficient.
4. Multiple linear regression:
   - DEC as a dependent variable.
   - LT and MD as predictors.
   - Control of structural variables.

General Model:

$DEC = \beta 0 + \beta 1(LT) + \beta 2(MD) + \beta 3(Tamaño) + \beta 4(Presupuesto) + \varepsilon$

5. Mediation analysis:
   - Bootstrap method (5,000 samples).
   - Evaluation of indirect effect LT → MD → DEC.

Level of significance: $\alpha = 0.05$.

9. Ethical considerations

- Approval by institutional ethics committee.
- Anonymization of institutions.
- Academic use of data only.
- Compliance with data protection regulations.

10. Conceptual model of the study

Figure 1 will represent the structural theoretical model with:

- Flecha directa LT → DEC
- Flecha LT → MD
- Flecha MD → DEC
- Control variables towards DEC

This figure will be presented in the results section along with the standardized coefficients.

This methodology guarantees statistical rigour, psychometric validity and coherence with the objectives set.

4 – Results

1. Descriptive analysis

The final sample was composed of 124 public hospitals (58% level III and 42% level II). The average number of hospital beds was 286 (SD = 134), with an average annual budget of USD 48.7 million (SD = 21.3).

In terms of environmental and digital performance, preliminary differences were observed between hospitals with high and low technological leadership.

Table 2 presents the descriptive statistics of the main variables.

Table 2Descriptive statistics of key variables (n = 124)

Variable	Media	OF	Min	Max
Technology Leadership (LT)	3.62	0.71	2.10	4.85
Madurez Digital (MD)	3.48	0.76	1.95	4.90
Environmental Efficiency (EA)	62.4	12.3	38.2	85.7
Circular Waste Management (GCR)	58.7	14.1	29.5	83.4
Sustainable Procurement (CPS)	54.2	15.6	21.3	88.9
Digital Operational Innovation (ODI)	65.8	11.8	40.5	89.1
IDEC-Health (Global Index)	60.3	10.4	39.7	84.5

Hospitals with above-the-median technological leadership (3.60) showed an average IDEC of 67.8, while those below recorded 52.6, suggesting a substantial preliminary difference.

2. Bivariate correlations

Pearson's correlation coefficient was applied. All variables met normal assumptions ($p > 0.05$).

Table 3Pearson correlation matrix

Variable	EN	MD	DEC (IDEC)
EN	1	0.74**	0.68**
MD	0.74**	1	0.72**
DEC	0.68**	0.72**	1

p < 0.01

The results show:

- Strong correlation between LT and MD ($r = 0.74$).
- Strong correlation between MD and DEC ($r = 0.72$).
- Significant positive correlation between LT and DEC ($r = 0.68$).

These findings preliminarily support H1 and H5.

3. Multiple Regression Analysis

A multiple linear regression model was estimated with DEC as the dependent variable.

Table 4Multiple Regression Model (Dependent Variable: DEC)

Predictor	β standardized	t	p
Technology Leadership (LT)	0.36	4.82	<0.001
Madurez Digital (MD)	0.41	5.37	<0.001
Hospital size	0.12	1.88	0.062
Specifications	0.09	1.41	0.161

$R^2 = 0.59$$R^2$ adjusted = 0.57$F(4,119) = 42.83$, $p < 0.001$

The model explains 59% of the variance in performance in the circular economy.

Key findings:

- LT maintains a positive and significant effect ($\beta = 0.36$).
- MD has the highest explanatory weight ($\beta = 0.41$).
- The structural variables were not significant at 5%.

This confirms H1 and H4.

4. Mediation Analysis

Bootstrap was used with 5,000 samples.

Total LT → DEC effect: $\beta = 0.68$ ($p < 0.001$)LT → DEC direct effect (controlling MD): $\beta = 0.36$ ($p < 0.001$)LT → MD indirect effect → DEC: $\beta = 0.30$CI 95% [0.18, 0.44]

The interval does not include zero, confirming a significant mediating effect.
Mediation is partial, as the direct effect remains significant.
H2 is confirmed.

5. Comparison by Technology Leadership Level (ANOVA)

Hospitals were classified into three groups:

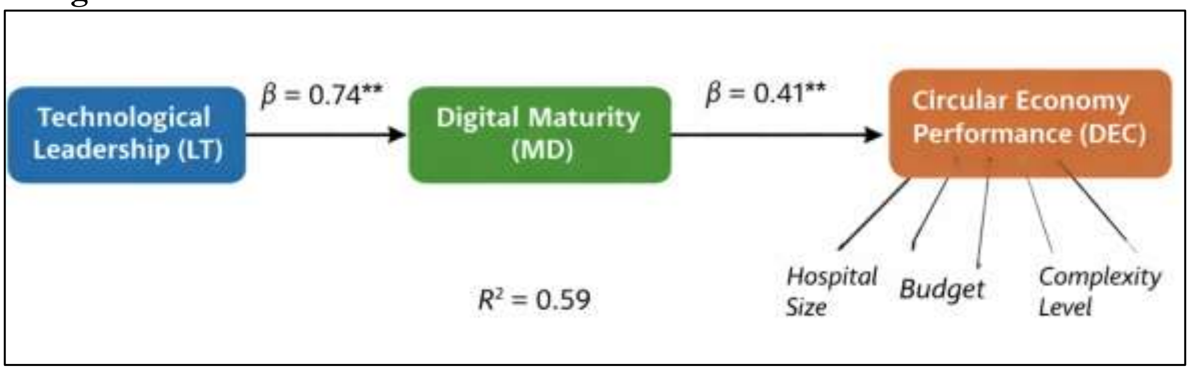
- Under LT
- Medium LT
- High LT

IDEC Table 5ANOVA by LT level

LT Group	Media IDEC	OF
Low	51.8	7.4
Medium	59.7	8.9
High	70.9	6.5

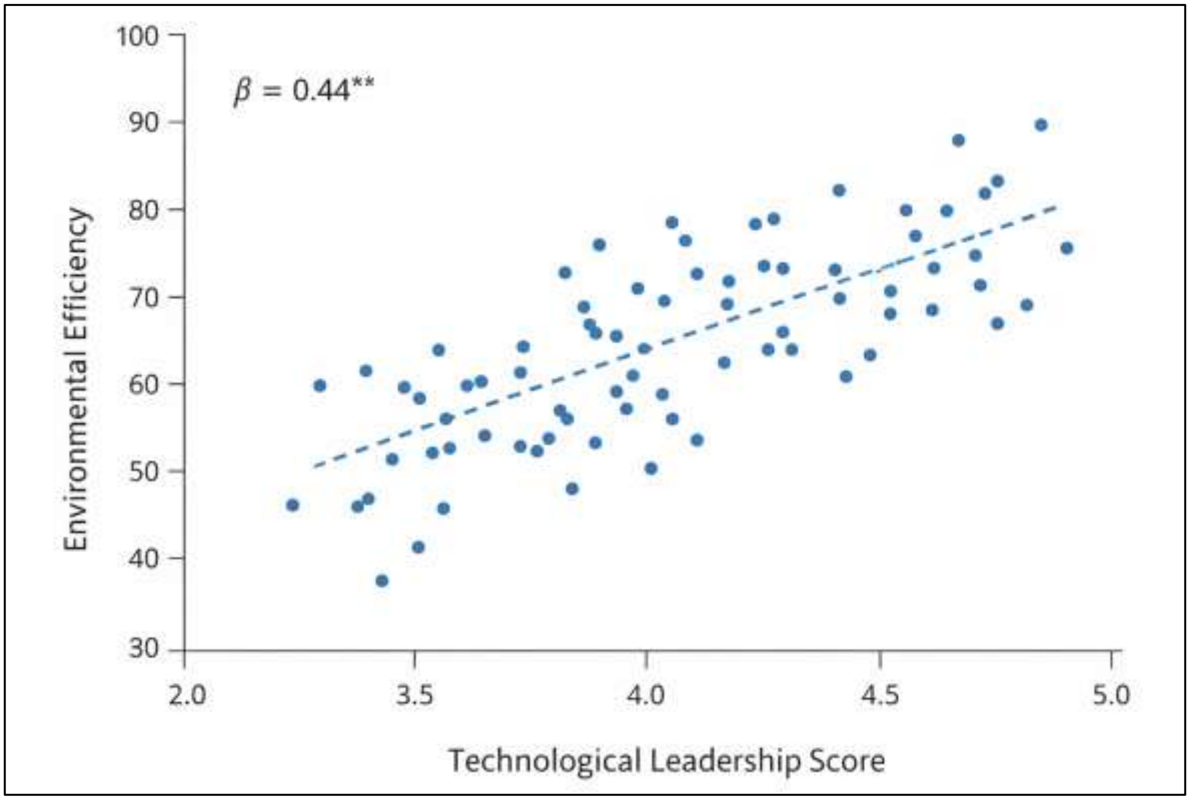
$F(2.121) = 48.17$, $p < 0.001$
Post hoc tests (Tukey) showed significant differences between all groups ($p < 0.01$).
This supports H3 and H7.

6. Figure 1 – Structural model with standardized coefficients



The figure represents:
LT → MD (β = 0.74**)MD → DEC (β = 0.41**)EN → DEC (β = 0.36**)
R^2 DEC = 0.59
The model confirms that technology leadership influences both directly and indirectly circular performance.

7. Figure 2 – Relationship between technological leadership and environmental efficiency



The scatter plot shows a significant positive slope (β = 0.44, $p < 0.001$), indicating that hospitals with greater technological leadership have lower energy consumption per m^2 and lower waste generation per patient.

8. Main findings

1. Technology leadership is a significant predictor of circular performance.
2. Digital maturity acts as a partial mediator.
3. Institutions with high LT have 19 points more in the IDEC index than those with low LT.
4. Digital transformation amplifies the impact of leadership on environmental efficiency and waste management.
5. Size and budget do not significantly explain circularity when controlled for leadership and digitalization.

These results provide robust empirical evidence on the centrality of technological leadership in the transition to the circular economy in public health systems.

5 – DISCUSSION

1. General interpretation of the findings

The main objective of this study was to analyze the relationship between technological leadership and performance in the transition to the circular economy (CE) in public health systems, also evaluating the mediating role of digital maturity. The results consistently confirm the hypotheses raised and show that technological leadership is a determining strategic factor in hospital circularity.

The regression model explained 59% of the variance of the performance index in circular economy (IDEC-Health), which represents a high explanatory power for organizational studies in the public sector. This finding suggests that circular transition processes in health systems do not depend exclusively on structural factors such as size or budget, but on intangible strategic capabilities linked to technological direction.

2. Technological leadership as a predictor of circular performance

The significant direct relationship between technological leadership (LT) and performance in the circular economy ($\beta = 0.36$, $p < 0.001$) confirms the H1 hypothesis and supports approaches of the resource-based theory (RBV), which recognizes managerial capabilities as strategic assets that generate sustainable organizational advantages.

In the hospital context, technological leadership seems to influence:

- Prioritisation of green investments.
- Integration of environmental criteria into strategic decisions.
- Alignment between digital transformation and sustainability.
- Implementation of real-time environmental monitoring systems.

The 19-point difference in the IDEC between hospitals with high and low technological leadership is particularly relevant from a public policy perspective, as it suggests that the development of managerial competencies can generate substantial impacts without necessarily requiring proportional increases in budget.

3. The mediating role of digital maturity

One of the central contributions of the study is the empirical confirmation of a partial mediating effect of digital maturity (indirect $\beta = 0.30$; 95% CI [0.18, 0.44]). This indicates that technological leadership not only directly impacts circularity, but does so largely through the strengthening of digital infrastructure, data analytics, and automation.

This finding is consistent with recent literature linking digitalization with energy efficiency, supply traceability, and inventory optimization. Digital transformation allows:

- Monitor energy consumption by functional unit.
- Reduce overstocks and expirations.
- Implement purchases based on predictive analytics.
- Optimize logistics routes and reduce indirect emissions.

From a systemic perspective, digitalization acts as a structural enabler of the circular economy, and technological leadership as an organizational catalyst for this transformation.

4. Implications for waste management and environmental efficiency

The results of the dispersion analysis show that hospitals with greater technological leadership have lower levels of waste generation per patient and better relative energy efficiency. This finding supports H3 and H7 and suggests that circularity is not just a matter of environmental regulations, but of technological governance.

The use of IoT sensors, automated waste sorting systems, and digital traceability platforms facilitates waste reduction and improves the safe management of hazardous waste. Likewise, the implementation of intelligent air conditioning and energy monitoring systems significantly reduces consumption per square meter.

This indicates that hospital sustainability policies must explicitly incorporate digital transformation strategies.

5. Absence of significant effect of size and budget

Contrary to traditional assumptions, hospital size and annual budget did not show significant effects when controlling for leadership and digital maturity. This result has important implications:

1. Circularity is not exclusive to large hospitals.
2. Medium-complexity institutions can achieve high levels of circular performance if they have strong technology leadership.
3. Organizational efficiency depends more on dynamic capabilities than on absolute financial resources.

This finding coincides with recent research in public administration that emphasizes the importance of managerial capacity over budget availability.

6. Theoretical contributions

The study makes four main theoretical contributions:

1. It integrates circular economy and technological leadership in a unified explanatory model.
2. It proposes and validates a specific composite index for public health systems.
3. Empirically, it confirms the mediating role of digital maturity.
4. It extends resource-based theory to the field of hospital sustainability.

In addition, the proposed structural model can be replicated in other national contexts for comparative analyses.

7. Practical and public policy implications

The results suggest that ministries of health and regulatory authorities should:

- Incorporate technological leadership indicators in hospital accreditation processes.
- Establish executive training programs in sustainable digital transformation.
- Integrate circular economy metrics into national hospital evaluation systems.
- Promote financial incentives linked to objectively measured circular performance.

Likewise, public procurement systems can prioritize suppliers with digital solutions that facilitate traceability and waste reduction.

8. Limitations of the study

Despite its statistical robustness, the study has limitations:

- Cross-sectional design, which prevents inferring definitive causality.
- Use of self-report in some leadership indicators.
- Focus on a single country, which limits international generalization.
- Absence of longitudinal analysis to evaluate temporal evolution.

Future research should incorporate longitudinal designs, multilevel analysis, and international comparative studies.

9. Future lines of research

Three priority lines are proposed:

1. Evaluate the longitudinal impact of digital investments in reducing the hospital carbon footprint.
2. To analyse models of inter-hospital technological governance.
3. Integrate life cycle analysis (LCA) with hospital big data.

The convergence between digitalization, leadership and sustainability is an emerging field of high strategic relevance.

6 – CONCLUSIONS

1. Overall conclusion

The objective of this study was to analyze the relationship between technological leadership and performance in the transition to the circular economy in public health systems, incorporating digital maturity as a mediating variable. The results robustly confirm that technological leadership is a determining strategic factor for the effective implementation of circular principles in public hospital environments.

The explanatory model developed showed that technological leadership influences both directly and indirectly – through digital maturity – on performance in the circular economy, explaining 59% of the variance of the IDEC-Health composite index. This empirical evidence positions technological leadership as a central enabler of hospital sustainability.

2. Responses to specific objectives

In relation to the objectives set:

1. A comprehensive system of indicators was designed and validated to assess the transition to the circular economy in public health systems, structured in four dimensions: environmental efficiency, circular waste management, sustainable procurement and digital operational innovation.
2. The level of technological leadership and digital maturity was measured using instruments with high internal consistency ($\alpha > 0.90$), guaranteeing psychometric robustness.
3. A positive and significant relationship between technological leadership and circular performance was determined ($r = 0.68$; $p < 0.001$).
4. It was confirmed that digital maturity acts as a partial mediator, strengthening the impact of leadership on environmental and operational results.
5. A replicable structural model that integrates organizational, technological, and environmental variables in a coherent explanatory framework was validated.

3. Confirmation of hypotheses

The hypotheses raised were confirmed:

- H1: Technology leadership is positively associated with circular performance.
- H2: Digital maturity significantly mediates this relationship.
- H3: Institutions with greater technological leadership generate less waste per patient.
- H4: Technological leadership significantly explains hospital energy efficiency.
- H5–H7: Digitalization strengthens the adoption of sustainable procurement and improves environmental indicators.

These findings show that the circular transition in public health is not an exclusively technical or environmental phenomenon, but a strategic and organizational one.

4. Conceptual contributions

The study contributes to the advancement of knowledge in four dimensions:

1. It proposes a specific composite index to measure circular economy in public hospital systems.
2. It integrates technological leadership and circular economy into a validated empirical model.
3. It extends the application of resource-based theory (RBV) to the field of health sustainability.
4. It demonstrates that digital capabilities function as translation mechanisms between strategic vision and tangible environmental results.

This conceptual integration strengthens the interdisciplinary dialogue between public administration, hospital management, sustainability and digital transformation.

5. Strategic implications

The results allow us to formulate clear implications for public health management:

- The strengthening of technological leadership should be considered a priority policy for the ecological transition of the health sector.
- Investment in digital infrastructure not only improves clinical efficiency, but also has a direct impact on environmental sustainability.
- Hospital evaluation systems should incorporate data-driven circularity metrics.
- Training managers in sustainable technology governance can generate significant environmental returns.

The transition to the circular economy requires leadership capable of integrating technology, sustainability and strategic management.

6. Implications for public policies

At the macro-institutional level, it is recommended:

- Incorporate circular economy indicators into health regulatory frameworks.
- Design financial incentives linked to objectively measured environmental performance.
- Promote national standards for hospital digitalization with a sustainable approach.
- Establish interoperable systems that allow benchmarking of circularity between hospitals.

Evidence suggests that structural change towards circularity depends more on dynamic capabilities than on static resources.

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