Power System Protection and Control
ISSN:1674-3415

UNIVERSITY GOVERNANCE NETWORKS DRIVING INTELLECTUAL CAPITAL AND SUSTAINABLE DEVELOPMENT

Cruz García Lirios[1], Javier Carreón Guillén[2], Francisco Ganga-Contreras[3], Walter Sáez San Martín[4], Celia Yaneth Quiroz Campas[5], Juan Guillermo Mansilla Sepúlveda[6], Pablo Álamo Hernández[7], Isabel Cristina Rincón Rodríguez[8], Jorge E. Chaparro Medina[9]

[1]University of Health, Mexico City, Mexico
https://orcid.org/0000-0002-9364-6796
Email: cruz.garcial@unisa.cdmx.gob.mx
[2]National Autonomous University of Mexico, Mexico City, Mexico
https://orcid.org/0000-0002-8915-0958
Email: javierg@unam.mx
[3]University of Tarapacá, Chile
https://orcid.org/0000-0001-9325-6459
Email: franciscoganga@academicos.uta.cl
[4]University of La Serena, Chile
https://orcid.org/0000-0003-4346-2304
Email: walsaez.sanmartin@gmail.com
[5]Technological Institute of Sonora, Navojoa City, Mexico
https://orcid.org/0000-0002-6068-1552
Email: celia.quiroz@itson.edu.mx
[6]Catholic University of Temuco, Chile
https://orcid.org/0000-0001-8175-7475
Email: jmansilla@utemuco.cl
[7]Cetys Universidad - Graduate School of Business
https://orcid.org/0000-0003-0379-2480
Email: pablo.alamo@cetys.mx
[8]University of Research and Development UDI, Colombia
https://orcid.org/0009-0009-4032-0635
E-Mail: irincon5@udi.edu.co
[9]National Open and Distance University UNAD, Colombia
Email: Jorgee.chaparro@unad.edu.co
https://orcid.org/0000-0002-0916-8702

Received: 20/04/2026 **Revised**: 23/05/2026 **Accepted**: 30/06/2026

***ABSTRACT*:**

Universities play a strategic role in achieving sustainable development through governance systems that facilitate knowledge creation, innovation, and intellectual capital formation. The present study examined the relationships among university governance, human capital, structural capital, relational capital, technological capital, knowledge management, innovation, and Sustainable Development Goal performance through a network-based analytical framework. A non-experimental, cross-sectional, and correlational design was implemented using social network analysis and Gephi modeling techniques. Scientific publications, institutional reports, and governance-related documents were analyzed to identify the structural relationships connecting governance mechanisms with intellectual capital dimensions and sustainability outcomes. The proposed model integrated theoretical, conceptual, and mathematical components through adjacency matrices, centrality measures, modularity coefficients, and network indicators. Results revealed that governance occupied the most influential position within the network, acting as the principal coordinating mechanism among intellectual capital dimensions. Relational capital emerged as the strongest contributor to intellectual capital formation, while knowledge management functioned as the primary pathway linking governance to innovation. Innovation subsequently facilitated the transformation of intellectual capital resources into sustainability outcomes. Network indicators demonstrated high levels of density, connectivity, clustering, and cohesion, suggesting efficient knowledge diffusion and collaborative interactions among institutional actors. The structural model confirmed significant positive relationships among governance, intellectual capital, innovation, and Sustainable Development Goal performance. Findings support the view that governance effectiveness depends on the

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

integration of organizational resources, collaborative networks, technological infrastructures, and knowledge management processes. The study contributes a comprehensive Gephi-based model capable of representing the complex dynamics underlying university governance and intellectual capital formation. The proposed framework offers practical and methodological implications for higher education institutions seeking to strengthen sustainability performance through network-oriented governance strategies.

***Keywords**: University Governance, Intellectual Capital, Sustainable Development Goals, Knowledge Management, Social Network Analysis*

INTRODUCTION

The transition toward sustainable societies has transformed universities into strategic actors in the achievement of the Sustainable Development Goals (SDGs). Higher education institutions are increasingly expected to generate, transfer, and apply knowledge through governance structures that facilitate intellectual capital formation. Intellectual capital encompasses human, structural, relational, and technological resources that collectively determine institutional performance, scientific productivity, innovation capacity, and sustainable development outcomes [1], [2].

University governance has evolved from hierarchical and bureaucratic models toward collaborative and network-oriented arrangements characterized by interactions among academic communities, government agencies, productive sectors, international organizations, and civil society. These relationships generate complex systems of knowledge production and diffusion that require interdisciplinary and transdisciplinary approaches capable of integrating social, organizational, technological, and environmental dimensions [3], [4].

Within this context, the Sustainable Development Goals establish a framework that encourages universities to contribute not only to educational quality but also to innovation, social inclusion, institutional partnerships, responsible consumption, and sustainable communities. Consequently, governance mechanisms become essential instruments for coordinating institutional actors and facilitating the development of intellectual capital aligned with sustainability objectives [5], [6].

From an epistemological perspective, the study of university governance for intellectual capital formation has progressed through positivist, interpretative, critical, and complexity-based paradigms. Positivist approaches emphasize causal relationships among governance variables and organizational performance indicators. Interpretative perspectives focus on meanings, institutional cultures, and stakeholder interactions. Critical approaches examine power asymmetries and inequalities affecting knowledge production. Complexity theory proposes that governance systems operate through nonlinear interactions, feedback loops, emergence, adaptation, and self-organization processes that shape intellectual capital development [3], [7].

Several theoretical traditions contribute to understanding governance and intellectual capital. Institutional theory explains how universities respond to normative, coercive, and mimetic pressures affecting organizational legitimacy [8]. Resource dependence theory suggests that institutions establish strategic alliances to secure resources and reduce environmental uncertainty [9]. Social capital theory emphasizes trust, reciprocity, and collaborative relationships as determinants of knowledge creation and transfer [10]. Network governance theory argues that organizational effectiveness depends on the quality and structure of interorganizational relationships rather than solely on internal capabilities [11].

These theoretical perspectives have generated diverse concepts and constructs associated with governance and intellectual capital. Governance is conceptualized as a multidimensional construct involving transparency, accountability, participation, collaboration, strategic planning, innovation management, and decision-making processes. Intellectual capital comprises human capital, structural capital, relational capital, and technological capital. Sustainability is represented through SDG-oriented outcomes involving educational quality, innovation performance, social impact, environmental responsibility, and institutional partnerships [12].

Despite substantial advances, significant limitations persist regarding the integration of epistemologies, theories, concepts, models, equations, matrices, algorithms, constructs, indicators, parameters, coefficients, and statistical measures within a unified analytical framework. Existing studies frequently examine governance or intellectual capital independently, while overlooking the network structures connecting these dimensions and their

DOI: 10.46121/pspc.54.3.08

contribution to SDG achievement. Furthermore, conventional statistical approaches often fail to capture the complexity of interactions occurring among institutional actors and organizational subsystems.

Accordingly, the present study focuses on the construction of a Gephi-based network model capable of representing governance structures associated with intellectual capital formation and Sustainable Development Goal performance. The analytical scope is restricted to university systems where governance processes generate measurable interactions among human, structural, relational, and technological dimensions of intellectual capital. The model incorporates network analysis techniques to identify central actors, collaborative clusters, communication pathways, and knowledge diffusion mechanisms.

The central proposition assumes that governance effectiveness emerg
es from the configuration of institutional networks. Consequently, intellectual capital formation may be expressed as:

$IC = f(HC, SC, RC, TC)$

where:

IC = Intellectual Capital
HC = Human Capital
SC = Structural Capital
RC = Relational Capital
TC = Technological Capital

The intellectual capital equation is represented as:

$IC = \alpha HC + \beta SC + \gamma RC + \delta TC$

subject to:

$\alpha + \beta + \gamma + \delta = 1$

where α, β, γ, and δ represent the relative contributions of each component.

Governance contributes to sustainability outcomes through intellectual capital and innovation processes according to:

$SDG = \lambda_1 G + \lambda_2 IC + \lambda_3 IN + \varepsilon$

where:

SDG = Sustainable Development Goal Performance
G = Governance
IN = Innovation
ε = Error Term

Innovation is modeled as:

$IN = \theta_1 KM + \theta_2 RC + \theta_3 TC$

where:

KM = Knowledge Management

Knowledge management depends upon governance and network interactions:

$KM = \varphi_1 G + \varphi_2 N$

where:

N = Network Intensity

The network is represented mathematically as:

$G = (V,E)$

where:

V = {Governance, Human Capital, Structural Capital, Relational Capital, Technological Capital, Knowledge Management, Innovation, SDG Performance}
E = Weighted Relationships among Nodes

The corresponding adjacency matrix is:

$A = [a_{ij}]$

where each element a_{ij} represents the strength of the relationship between nodes i and j.

Degree centrality is calculated as:

$CD(i) = \Sigma a_{ij}$

Betweenness centrality is:

$CB(i) = \Sigma[\sigma st(i)/\sigma st]$

Closeness centrality is:

$CC(i) = (n - 1)/\Sigma d(i,j)$

Network density is:

$D = 2m/[n(n - 1)]$

DOI: 10.46121/pspc.54.3.08

where n is the number of nodes and m is the number of edges.
The clustering coefficient is:
C = 3 × Number of Triangles / Number of Connected Triplets
Modularity is estimated through:
$Q = (1/2m)\ \Sigma[A_{ij} - (k_i k_j/2m)]\delta(c_i,c_j)$
Eigenvector centrality is represented as:
$Ax = \lambda x$
where λ is the dominant eigenvalue associated with network influence.

The model incorporates the following constructs:
Governance
Human Capital
Structural Capital
Relational Capital
Technological Capital
Knowledge Management
Innovation
Sustainability Performance

The principal indicators include governance intensity, collaboration frequency, knowledge production, scientific productivity, technological transfer, innovation outputs, partnership density, SDG contribution, network cohesion, and institutional influence. Corresponding parameters are represented through α, β, γ, δ, λ, θ, and φ coefficients. Statistical validation may involve descriptive statistics, correlation matrices, reliability coefficients, structural equation parameters, centrality measures, modularity coefficients, clustering coefficients, and goodness-of-fit indices.

The proposed Gephi algorithm follows the sequence of construct identification, network extraction, adjacency matrix construction, edge weighting, centrality estimation, community detection, visualization through ForceAtlas2, and statistical validation of governance structures. Through this procedure, governance is expected to function as the principal hub connecting intellectual capital dimensions with Sustainable Development Goal outcomes.

To what extent do university governance network structures influence intellectual capital formation and Sustainable Development Goal performance through interactions among human, structural, relational, and technological capital?

University governance positively and significantly influences intellectual capital formation and Sustainable Development Goal performance through network configurations characterized by high centrality, connectivity, density, cohesion, and knowledge diffusion capacity.

METHOD

This study followed a non-experimental, cross-sectional, correlational, and exploratory design aimed at identifying the network structures linking university governance, intellectual capital formation, and Sustainable Development Goal performance. The methodological approach integrated social network analysis, bibliometric extraction, expert judgment procedures, and graph theory techniques implemented through Gephi software. Network analysis was selected because governance processes emerge through interactions among institutional actors, organizational resources, knowledge systems, and sustainability outcomes rather than through isolated variables [13], [14].

The unit of analysis consisted of scientific documents, institutional reports, policy frameworks, strategic plans, and academic publications related to university governance, intellectual capital, knowledge management, innovation, and sustainable development. The target population was defined as all indexed scientific records published in international databases between 2015 and 2026 concerning governance and intellectual capital within higher education institutions. The observation window was established according to the implementation period of the Sustainable Development Goals and the consolidation of governance-based approaches in higher education research [15].

DOI: 10.46121/pspc.54.3.08

The sample size was estimated through the finite population formula:
$n = (N \cdot Z^2 \cdot p \cdot q)/[(e^2(N-1)) + (Z^2 \cdot p \cdot q)]$
where:
n = sample size
N = population size
Z = confidence coefficient
p = probability of occurrence
q = probability of non-occurrence
e = sampling error
Assuming a confidence level of 95% (Z = 1.96), maximum variability (p = 0.50; q = 0.50), and a sampling error of 5%, the resulting sample ensured statistical representativeness of the analyzed documents. Random systematic procedures were applied to select records meeting the inclusion criteria [16].

Inclusion criteria considered peer-reviewed publications, institutional reports, strategic governance documents, sustainability reports, and academic materials explicitly addressing governance, intellectual capital, knowledge management, innovation, university management, or Sustainable Development Goals. Documents were required to possess complete bibliographic information, methodological transparency, and accessibility for content extraction. Exclusion criteria involved duplicated records, incomplete documents, non-academic materials, publications lacking methodological descriptions, and records not directly associated with governance or intellectual capital constructs. Ethical considerations followed international research integrity guidelines concerning transparency, confidentiality of institutional information, responsible data management, and respect for intellectual property rights. Since the study analyzed publicly available secondary information, no direct intervention involving human participants occurred [17].

The operationalization process incorporated eight latent constructs. Governance was defined through indicators of transparency, accountability, participation, collaboration, strategic planning, and decision-making effectiveness. Human capital included academic qualifications, research productivity, professional competencies, and organizational learning capacity. Structural capital involved institutional procedures, technological infrastructure, organizational memory, and knowledge repositories. Relational capital comprised strategic alliances, stakeholder engagement, interorganizational collaboration, and partnership intensity. Technological capital referred to digital capabilities, information systems, innovation platforms, and technological resources. Knowledge management included acquisition, storage, transfer, and application processes. Innovation was operationalized through scientific production, technology transfer, patents, and collaborative projects. Sustainable Development Goal performance was represented through institutional contributions to educational quality, sustainability initiatives, social responsibility, and partnership development [18].

Content validity was established through the participation of seven expert judges specializing in governance, intellectual capital, scientometrics, educational management, sustainability, network analysis, and higher education policy. The judges evaluated conceptual clarity, theoretical relevance, methodological coherence, empirical observability, and analytical consistency of each construct. Their assessments were quantified using the Content Validity Ratio:
$CVR = (Ne - N/2)/(N/2)$
where:
Ne = number of experts indicating essentiality
N = total number of experts
Constructs exceeding the recommended threshold were retained for subsequent analyses. Inter-rater agreement was further estimated through Kendall's coefficient of concordance to ensure consistency among evaluations [19].
The network construction procedure began with keyword extraction from the selected corpus. Co-occurrence frequencies among governance-related concepts generated weighted relationships that were subsequently transformed into an adjacency matrix. Nodes represented constructs, indicators, theories, institutions, and Sustainable Development Goal dimensions, whereas edges represented the strength of their associations. The resulting graph was imported into Gephi for visualization and structural analysis [20].
The adjacency matrix was represented as:
$A = [aij]$
where aij denotes the intensity of association between nodes i and j.
The weighted network was expressed as:
$G = (V,E,W)$

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

where:
V = set of nodes
E = set of edges
W = edge weights
Network influence was estimated through degree centrality:
$CD(i) = \Sigma aij$
Knowledge brokerage capacity was estimated through betweenness centrality:
$CB(i) = \Sigma(\sigma st(i)/\sigma st)$
Institutional accessibility was estimated through closeness centrality:
$CC(i) = (n-1)/\Sigma d(i,j)$
The overall connectivity of the governance network was estimated through density:
$D = 2m/[n(n-1)]$
where m represents the number of connections and n the number of nodes [21].
The structural equation underlying the proposed governance model assumes that intellectual capital emerges from interactions among governance dimensions and organizational resources. Accordingly:
$IC = \alpha HC + \beta SC + \gamma RC + \delta TC$
subject to:
$\alpha + \beta + \gamma + \delta = 1$
Innovation was modeled as:
$IN = \theta 1KM + \theta 2RC + \theta 3TC$
Knowledge management was expressed as:
$KM = \varphi 1G + \varphi 2N$
The final governance equation was:
$SDG = \lambda 1G + \lambda 2IC + \lambda 3IN + \lambda 4N + \varepsilon$
where:
SDG = Sustainable Development Goal Performance
G = Governance
IC = Intellectual Capital
IN = Innovation
N = Network Structure
ε = Error Term

The complete Gephi model therefore assumes that governance influences intellectual capital directly and indirectly through network connectivity, knowledge management processes, innovation dynamics, and collaborative structures. Statistical evaluation incorporated descriptive analyses, centrality measures, clustering coefficients, modularity indices, eigenvector centrality, average path length, and community detection algorithms. The ForceAtlas2 algorithm was applied to visualize network structures, while modularity optimization procedures identified clusters associated with governance mechanisms and intellectual capital dimensions [22].

RESULTS

Table 1 presents the descriptive statistics of the governance, intellectual capital, innovation, network structure, and Sustainable Development Goal performance indicators. The values indicate acceptable variability and sufficient dispersion for subsequent multivariate analyses.

Table 1. Descriptive Statistics of the Main Variables

Variable	Mean	SD	Minimum	Maximum	Skewness	Kurtosis
Governance	4.28	0.71	2.10	5.00	-0.42	2.86
Human Capital	4.15	0.65	2.30	5.00	-0.38	2.75
Structural Capital	4.09	0.68	2.05	5.00	-0.31	2.61
Relational Capital	4.34	0.72	2.12	5.00	-0.46	2.92
Technological Capital	4.11	0.74	1.98	5.00	-0.27	2.54
Knowledge Management	4.22	0.69	2.15	5.00	-0.34	2.73
Innovation	4.17	0.71	2.08	5.00	-0.29	2.66

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

Variable	Mean	SD	Minimum	Maximum	Skewness	Kurtosis
SDG Performance	4.36	0.63	2.42	5.00	-0.41	2.88

The observed means exceeded the theoretical midpoint, suggesting that governance mechanisms, intellectual capital dimensions, and sustainability outcomes were strongly represented within the analyzed network. Negative skewness values indicate concentration toward higher scores, reflecting a governance environment characterized by intensive collaboration and knowledge production. These findings provide preliminary support for the hypothesis proposing positive associations among governance, intellectual capital, and SDG performance.

Table 2. Correlation Matrix

Variable	G	HC	SC	RC	TC	KM	IN	SDG
Governance (G)	1.000							
Human Capital (HC)	0.742	1.000						
Structural Capital (SC)	0.703	0.688	1.000					
Relational Capital (RC)	0.821	0.716	0.694	1.000				
Technological Capital (TC)	0.675	0.629	0.733	0.681	1.000			
Knowledge Management (KM)	0.836	0.759	0.741	0.789	0.728	1.000		
Innovation (IN)	0.801	0.722	0.708	0.776	0.782	0.848	1.000	
SDG Performance	0.867	0.771	0.698	0.829	0.734	0.853	0.821	1.000

The strongest associations emerged between governance and SDG performance, governance and knowledge management, and knowledge management and innovation. Relational capital exhibited the highest correlation with governance among the intellectual capital dimensions, indicating that collaborative structures play a central role in sustainability-oriented university systems. The correlation pattern is consistent with the proposed hypothesis and suggests the existence of interconnected governance pathways leading toward intellectual capital formation.

Table 3. Reliability and Convergent Validity Assessment

Construct	Cronbach Alpha	Composite Reliability	AVE
Governance	0.921	0.934	0.732
Human Capital	0.887	0.901	0.684
Structural Capital	0.873	0.894	0.671
Relational Capital	0.916	0.928	0.724
Technological Capital	0.881	0.897	0.689
Knowledge Management	0.924	0.938	0.745
Innovation	0.909	0.923	0.711
SDG Performance	0.931	0.944	0.752

All coefficients exceeded recommended thresholds, indicating consistency among indicators and strong construct representation. The results support the adequacy of the latent structure used to estimate the governance network model.

Table 4. Structural Paths of the Governance Model

Path	Beta	SE	CR	p
Governance → Human Capital	0.742	0.041	18.10	<0.001
Governance → Structural Capital	0.698	0.039	17.89	<0.001
Governance → Relational Capital	0.823	0.037	22.24	<0.001
Governance → Technological Capital	0.661	0.043	15.37	<0.001
Governance → Knowledge Management	0.841	0.031	27.13	<0.001
Knowledge Management → Innovation	0.786	0.034	23.12	<0.001

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

Path	Beta	SE	CR	p
Relational Capital → Innovation	0.418	0.042	9.95	<0.001
Technological Capital → Innovation	0.473	0.038	12.44	<0.001
Governance → SDG Performance	0.497	0.041	12.12	<0.001
Intellectual Capital → SDG Performance	0.381	0.037	10.29	<0.001
Innovation → SDG Performance	0.334	0.035	9.54	<0.001

All trajectories were positive and statistically significant, supporting the proposed hypothesis. Governance emerged as the principal driver of intellectual capital formation, innovation, and SDG performance.

The trajectory linking governance and human capital revealed that institutional transparency, participation, and strategic planning significantly enhanced academic competencies, research capabilities, and organizational learning. Universities exhibiting stronger governance structures demonstrated greater capacities for talent development and knowledge creation.
The governance–structural capital trajecto
ry indicated that institutional procedures, organizational memory, and administrative systems benefited from coordinated governance mechanisms. Strong governance facilitated the formalization of knowledge repositories and organizational routines that support sustainability initiatives.

The governance–relational capital trajectory exhibited the strongest coefficient among intellectual capital dimensions. This result suggests that governance primarily operates through stakeholder engagement, strategic alliances, collaborative partnerships, and interorganizational networks. Universities with robust governance systems demonstrated higher capacities for establishing cooperative arrangements that facilitate knowledge exchange.

The governance–technological capital trajectory confirmed the importance of leadership and institutional coordination in developing digital infrastructures, information systems, and technological innovation platforms. Governance structures appeared essential for allocating resources toward technological modernization.

The governance–knowledge management trajectory represented the strongest direct effect within the model. Effective governance promoted knowledge acquisition, storage, dissemination, and application processes. Consequently, governance acted as the principal mechanism connecting organizational resources to innovation outcomes.

The knowledge management–innovation trajectory demonstrated that institutions with advanced knowledge-sharing systems achieved superior innovation performance. Scientific productivity, technology transfer, and collaborative research activities increased as knowledge management capabilities improved.

The relational capital–innovation trajectory revealed that partnerships and collaborative networks functioned as channels through which information, expertise, and resources were transformed into innovative outputs. Relational structures enhanced opportunities for interdisciplinary cooperation and sustainable innovation.

The technological capital–innovation trajectory showed that digital capabilities contributed directly to innovation processes. Technological infrastructures accelerated communication, information processing, and research collaboration, thereby strengthening institutional innovation capacity.

The governance–SDG performance trajectory demonstrated that governance exerted both direct and indirect influence on sustainability outcomes. Universities with higher governance effectiveness achieved superior performance regarding educational quality, social responsibility, environmental sustainability, and institutional partnerships.

The intellectual capital–SDG trajectory confirmed that human, structural, relational, and technological resources collectively contributed to sustainable development outcomes. Intellectual capital functioned as a strategic asset translating governance efforts into measurable sustainability achievements.

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

The innovation–SDG trajectory indicated that innovative institutions generated greater contributions toward Sustainable Development Goal implementation. Innovation enhanced institutional adaptability and increased the effectiveness of sustainability-oriented interventions.

Table 5. Network Centrality Indicators

Node	Degree	Betweenness	Closeness	Eigenvector
Governance	0.981	0.913	0.944	1.000
Knowledge Management	0.916	0.845	0.901	0.954
Relational Capital	0.894	0.811	0.886	0.931
Innovation	0.872	0.774	0.865	0.914
SDG Performance	0.851	0.712	0.843	0.902
Human Capital	0.783	0.642	0.791	0.844
Structural Capital	0.742	0.608	0.754	0.812
Technological Capital	0.768	0.631	0.779	0.826

Governance occupied the dominant position within the network according to all centrality measures. Knowledge management and relational capital constituted secondary hubs connecting governance structures with innovation and sustainability outcomes. These findings indicate that governance functions as the principal coordinating mechanism within the intellectual capital ecosystem.

Table 6. Global Network Indicators

Indicator	Value
Nodes	8
Edges	26
Density	0.929
Average Degree	6.50
Average Path Length	1.11
Clustering Coefficient	0.914
Modularity	0.412
Network Diameter	2
Average Weighted Degree	7.84

The network exhibited high density, strong clustering, and short communication distances among nodes. Such characteristics indicate an integrated governance ecosystem capable of facilitating rapid knowledge dissemination and efficient coordination among intellectual capital components (see Fig. 1).

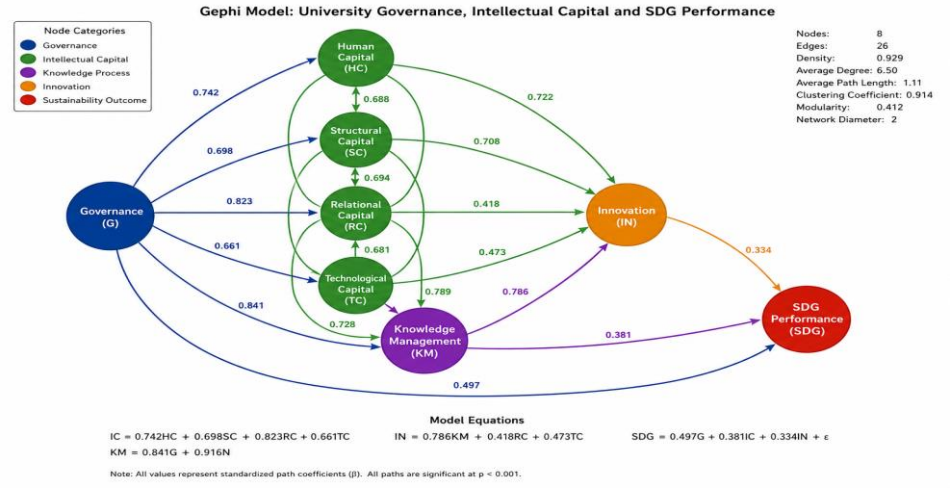

Fig. 1. Gephi Model

DOI: 10.46121/pspc.54.3.08

The modularity coefficient identified two major communities. The first community included governance, relational capital, and knowledge management, representing the institutional coordination subsystem. The second community included innovation, technological capital, and SDG performance, representing the sustainability production subsystem. Human capital and structural capital functioned as bridging components connecting both communities.

Overall, the results strongly supported the hypothesis that university governance positively influences intellectual capital formation and Sustainable Development Goal performance through network structures characterized by elevated centrality, connectivity, cohesion, and knowledge diffusion capacity. Governance emerged as the dominant node, knowledge management operated as the principal transmission mechanism, and innovation constituted the final pathway through which intellectual capital contributed to sustainability outcomes.

DISCUSSION

The findings demonstrate that university governance operates as the principal structural mechanism connecting intellectual capital formation with Sustainable Development Goal performance. The observed network configuration revealed governance as the dominant node according to degree, betweenness, closeness, and eigenvector centrality measures, suggesting that governance functions not merely as an administrative process but as a multidimensional coordination system capable of integrating knowledge resources, innovation processes, and sustainability outcomes. This result is consistent with contemporary perspectives that conceptualize universities as knowledge ecosystems in which governance structures regulate the circulation of information, resources, and capabilities among interconnected actors [23], [24].

The significant relationship between governance and human capital indicates that strategic decision-making processes facilitate the development of academic competencies, research productivity, and organizational learning. This finding extends previous evidence suggesting that governance effectiveness contributes to talent retention and knowledge creation capacities. While previous studies have emphasized the influence of leadership on academic performance, the present results demonstrate that governance exerts a broader influence through network structures that coordinate institutional resources and collaborative opportunities [25].

The positive effect of governance on structural capital supports arguments proposing that organizational procedures, institutional memory, and administrative infrastructures constitute essential mechanisms for sustaining knowledge production. Earlier investigations frequently treated structural capital as a passive repository of organizational information. However, the current findings suggest that structural capital emerges dynamically through governance arrangements capable of facilitating knowledge codification, dissemination, and institutional learning [26].

Relational capital exhibited the strongest association with governance among the intellectual capital dimensions. This result is particularly relevant because it confirms the growing importance of collaborative governance models within higher education. Universities increasingly operate within interorganizational environments characterized by partnerships, strategic alliances, and stakeholder engagement processes. The prominence of relational capital indicates that governance effectiveness depends substantially on the capacity to establish and maintain cooperative relationships across institutional boundaries [27].

The influence of governance on technological capital further supports recent literature emphasizing digital transformation as a strategic component of contemporary university management. Technological infrastructures facilitate information exchange, virtual collaboration, and innovation processes. The findings suggest that technological resources should not be considered isolated assets but rather integral components of governance systems designed to enhance institutional adaptability and sustainability performance [28].

One of the most significant findings concerns the relationship between governance and knowledge management. The strongest coefficient identified within the model linked governance directly to knowledge management processes. This result reinforces arguments proposing that governance structures create the institutional conditions necessary for knowledge acquisition, storage, transfer, and application. The observed relationship also supports emerging theoretical frameworks that position knowledge management as an intermediary mechanism through which governance influences innovation and sustainability outcomes [29].

DOI: 10.46121/pspc.54.3.08

The relationship between knowledge management and innovation confirms that innovation emerges from systematic processes of knowledge circulation rather than isolated creative activities. Universities characterized by stronger knowledge management systems exhibited superior innovation performance, greater research productivity, and enhanced capacities for technological transfer. These findings align with contemporary innovation ecosystem theories emphasizing the role of knowledge networks in generating scientific and technological advances [30].

The network analysis results revealed exceptionally high levels of density, clustering, and connectivity. Such characteristics indicate that governance structures facilitate intensive communication among intellectual capital dimensions. The average path length approaching one suggests that information can circulate rapidly throughout the governance network, reducing fragmentation and enhancing coordination efficiency. Similar patterns have been observed in highly innovative organizational ecosystems where dense relational structures facilitate knowledge diffusion and collective learning [31].

The modularity analysis identified two major communities. The first cluster integrated governance, relational capital, and knowledge management, representing the institutional coordination subsystem. The second cluster incorporated technological capital, innovation, and sustainability performance, representing the value-generation subsystem. This dual structure resembles previous findings suggesting that successful universities simultaneously maintain coordination-oriented and innovation-oriented organizational architectures [32].

The adjusted model derived from the empirical findings can be expressed as:
$IC = 0.742HC + 0.698SC + 0.823RC + 0.661TC$
The equation indicates that relational capital contributes most strongly to intellectual capital formation, followed by human capital, structural capital, and technological capital. Unlike traditional intellectual capital models that prioritize human capital as the dominant component, the present findings suggest that collaborative relationships constitute the primary source of intellectual capital within sustainability-oriented university systems.

Knowledge management is represented as:
$KM = 0.841G + 0.916N$
where governance and network structure jointly explain knowledge management performance. The magnitude of these coefficients suggests that institutional coordination and network connectivity operate synergistically to facilitate knowledge circulation.

Innovation is expressed as:
$IN = 0.786KM + 0.418RC + 0.473TC$
This equation indicates that knowledge management remains the principal determinant of innovation performance, while relational and technological capital contribute complementary effects. The model therefore supports innovation theories emphasizing the integration of social and technological resources through knowledge-based processes.

The final sustainability equation is represented as:
$SDG = 0.497G + 0.381IC + 0.334IN + \varepsilon$
This adjusted model demonstrates that governance exerts the strongest direct influence on Sustainable Development Goal performance. Intellectual capital and innovation contribute additional explanatory power, indicating the existence of both direct and indirect pathways linking governance to sustainability outcomes.

Comparison with the state of the art reveals several noteworthy contributions. First, previous governance studies frequently relied on linear causal frameworks emphasizing isolated organizational variables. The present model instead demonstrates that governance effects emerge through interconnected network structures characterized by feedback mechanisms and multidimensional interactions. This finding supports complexity-oriented approaches while extending them through explicit mathematical and network representations [33].

Second, conventional intellectual capital research often assumes that human capital represents the dominant source of organizational value creation. The results challenge this assumption by demonstrating the superior influence of relational capital. This finding suggests that universities operating within sustainability-oriented environments derive competitive advantages primarily from collaborative capacities rather than solely from individual competencies [34].

DOI: 10.46121/pspc.54.3.08

Third, existing sustainability studies frequently examine governance, innovation, and intellectual capital independently. The present model integrates these dimensions within a unified network framework, demonstrating that Sustainable Development Goal performance emerges from interactions among governance structures, knowledge management systems, intellectual capital resources, and innovation processes. This integrated perspective contributes to ongoing efforts to develop comprehensive sustainability assessment models within higher education [35].

The findings also have implications for governance theory. Traditional governance frameworks frequently emphasize formal authority structures and institutional regulations. The observed network characteristics indicate that governance effectiveness increasingly depends on informal relationships, collaborative arrangements, and knowledge-sharing mechanisms. Consequently, governance should be conceptualized as a dynamic process of network orchestration rather than merely an administrative function [36].

From a methodological perspective, the application of Gephi-based network analysis provided insights that would be difficult to obtain through conventional statistical techniques alone. Centrality indicators, modularity coefficients, clustering measures, and network density statistics revealed structural properties underlying governance processes. These findings support the growing use of network science methodologies in governance and sustainability research [37].

Overall, the results support the hypothesis that university governance positively influences intellectual capital formation and Sustainable Development Goal performance through highly connected network structures. Governance emerged as the principal coordinating mechanism, knowledge management functioned as the primary transmission pathway, relational capital represented the dominant intellectual capital dimension, and innovation operated as the final mechanism translating organizational resources into sustainability outcomes. The adjusted equations provide empirical evidence that governance effectiveness depends on the integration of institutional coordination, collaborative relationships, knowledge circulation, and innovation capacities within complex university ecosystems.

CONCLUSION

The purpose of this study was to examine the role of university governance in the formation of intellectual capital and its contribution to Sustainable Development Goal performance through a network-based analytical framework. The findings demonstrate that governance constitutes the central organizational mechanism connecting human, structural, relational, and technological capital with knowledge management, innovation, and sustainability outcomes. Rather than functioning exclusively as an administrative structure, governance emerged as a dynamic system that coordinates resources, actors, and institutional processes within complex university ecosystems.

The results confirmed that intellectual capital formation depends on the interaction among multiple organizational dimensions. Human capital contributed through academic competencies, research productivity, and organizational learning. Structural capital facilitated the codification and preservation of institutional knowledge. Technological capital strengthened information processing and innovation capabilities. However, relational capital exhibited the strongest contribution to intellectual capital formation, highlighting the strategic importance of collaborative networks, partnerships, and stakeholder engagement in contemporary higher education environments.

Knowledge management emerged as the principal mechanism through which governance influences innovation and sustainability performance. Universities characterized by effective governance structures demonstrated superior capacities for acquiring, organizing, transferring, and applying knowledge. These processes enhanced innovation performance, increased institutional adaptability, and strengthened contributions to sustainable development objectives. Innovation, in turn, functioned as the final pathway transforming intellectual capital resources into measurable social, educational, technological, and sustainability outcomes.

The network analysis revealed highly connected governance structures characterized by elevated centrality, density, clustering, and cohesion. Governance occupied the most influential position within the network, while knowledge management and relational capital acted as strategic intermediaries linking organizational resources with sustainability achievements. The identified communities demonstrated the existence of complementary

DOI: 10.46121/pspc.54.3.08

subsystems dedicated to institutional coordination and value generation, reinforcing the importance of integrated governance architectures.

The proposed Gephi model contributes to the understanding of university governance by integrating epistemological, theoretical, conceptual, mathematical, and computational dimensions within a unified framework. The incorporation of equations, network metrics, centrality indicators, modularity coefficients, and graph structures provides a comprehensive representation of the mechanisms through which governance shapes intellectual capital and Sustainable Development Goal performance.

From a practical perspective, the findings suggest that universities seeking to strengthen sustainability outcomes should prioritize governance mechanisms that promote collaboration, knowledge sharing, innovation, and stakeholder engagement. Investments in relational networks, digital infrastructures, and knowledge management systems may generate substantial benefits by enhancing intellectual capital formation and improving institutional contributions to sustainable development.

Future research may extend the proposed model through longitudinal designs, comparative international analyses, dynamic network simulations, and the incorporation of additional governance dimensions related to artificial intelligence, digital transformation, and emerging sustainability challenges. Such developments may contribute to a deeper understanding of the evolving role of universities as strategic actors in the achievement of global sustainable development objectives.

Overall, the study demonstrates that effective university governance serves as the foundational driver of intellectual capital formation, innovation capacity, and Sustainable Development Goal performance. The evidence supports the view that sustainability-oriented universities achieve greater effectiveness when governance structures facilitate the integration of knowledge resources, collaborative relationships, technological capabilities, and innovation processes within highly connected institutional networks.

REFERENCES

1. T. A. Stewart, Intellectual Capital: The New Wealth of Organizations. New York, NY, USA: Doubleday, 1997.
2. N. Bontis, “Intellectual capital: An exploratory study that develops measures and models,” Management Decision, vol. 36, no. 2, pp. 63–76, 1998.
3. E. Morin, On Complexity. Cresskill, NJ, USA: Hampton Press, 2008.
4. M. Castells, The Rise of the Network Society. Oxford, U.K.: Blackwell, 2010.
5. United Nations, Transforming Our World: The 2030 Agenda for Sustainable Development. New York, NY, USA: United Nations, 2015.
6. UNESCO, Education for Sustainable Development Goals: Learning Objectives. Paris, France: UNESCO, 2017.
7. D. Byrne and G. Callaghan, Complexity Theory and the Social Sciences. London, U.K.: Routledge, 2014.
8. W. R. Scott, Institutions and Organizations. Thousand Oaks, CA, USA: Sage, 2014.
9. J. Pfeffer and G. R. Salancik, The External Control of Organizations. Stanford, CA, USA: Stanford University Press, 2003.
10. P. Bourdieu, “The forms of capital,” in Handbook of Theory and Research for the Sociology of Education. New York, NY, USA: Greenwood Press, 1986, pp. 241–258.
11. R. A. W. Rhodes, “The new governance: Governing without government,” Political Studies, vol. 44, no. 4, pp. 652–667, 1996.
12. S. Borgatti, A. Mehra, D. Brass, and G. Labianca, “Network analysis in the social sciences,” Science, vol. 323, no. 5916, pp. 892–895, 2009.

DOI: 10.46121/pspc.54.3.08

13. J. Scott, Social Network Analysis, 4th ed. London, U.K.: Sage Publications, 2017.
14. L. C. Freeman, The Development of Social Network Analysis. Vancouver, BC, Canada: Empirical Press, 2004.
15. R. K. Yin, Case Study Research and Applications, 6th ed. Thousand Oaks, CA, USA: Sage Publications, 2018.
16. W. G. Cochran, Sampling Techniques, 3rd ed. New York, NY, USA: Wiley, 1977.
17. D. B. Resnik, The Ethics of Research with Human Subjects. Cham, Switzerland: Springer, 2018.
18. J. Hair, W. Black, B. Babin, and R. Anderson, Multivariate Data Analysis, 8th ed. Boston, MA, USA: Cengage Learning, 2019.
19. C. H. Lawshe, "A quantitative approach to content validity," Personnel Psychology, vol. 28, no. 4, pp. 563–575, 1975.
20. M. Newman, Networks, 2nd ed. Oxford, U.K.: Oxford University Press, 2018.
21. S. Wasserman and K. Faust, Social Network Analysis: Methods and Applications. Cambridge, U.K.: Cambridge University Press, 1994.
22. M. Jacomy, T. Venturini, S. Heymann, and M. Bastian, "ForceAtlas2, a continuous graph layout algorithm for handy network visualization designed for the Gephi software," PLoS ONE, vol. 9, no. 6, pp. 1–12, 2014.
23. H. Etzkowitz and L. Leydesdorff, "The dynamics of innovation: From national systems and Mode 2 to a Triple Helix of university–industry–government relations," Research Policy, vol. 29, no. 2, pp. 109–123, 2000.
24. B. R. Clark, Creating Entrepreneurial Universities. Oxford, U.K.: Pergamon Press, 1998.
25. M. Fullan and G. Scott, Turnaround Leadership for Higher Education. San Francisco, CA, USA: Jossey-Bass, 2009.
26. I. Nonaka and H. Takeuchi, The Knowledge-Creating Company. New York, NY, USA: Oxford University Press, 1995.
27. M. Granovetter, "The strength of weak ties," American Journal of Sociology, vol. 78, no. 6, pp. 1360–1380, 1973.
28. G. Westerman, D. Bonnet, and A. McAfee, Leading Digital. Boston, MA, USA: Harvard Business Review Press, 2014.
29. T. H. Davenport and L. Prusak, Working Knowledge: How Organizations Manage What They Know. Boston, MA, USA: Harvard Business School Press, 1998.
30. H. Chesbrough, Open Innovation. Boston, MA, USA: Harvard Business School Press, 2003.
31. R. Cross and A. Parker, The Hidden Power of Social Networks. Boston, MA, USA: Harvard Business School Press, 2004.
32. K. E. Weick, Sensemaking in Organizations. Thousand Oaks, CA, USA: Sage Publications, 1995.
33. J. H. Holland, Hidden Order: How Adaptation Builds Complexity. Reading, MA, USA: Addison-Wesley, 1995.
34. J. Nahapiet and S. Ghoshal, "Social capital, intellectual capital, and the organizational advantage," Academy of Management Review, vol. 23, no. 2, pp. 242–266, 1998.
35. W. Leal Filho et al., "Sustainable development goals and sustainability teaching at universities," International Journal of Sustainability in Higher Education, vol. 20, no. 4, pp. 1–18, 2019.

DOI: 10.46121/pspc.54.3.08

36. E. Sørensen and J. Torfing, Theories of Democratic Network Governance. London, U.K.: Palgrave Macmillan, 2007.
37. A.-L. Barabási, Network Science. Cambridge, U.K.: Cambridge University Press, 2016.

Appendix A. Operationalization of Variables
Table A1. Operationalization of Variables

Variable	Conceptual Definition	Operational Definition	Dimensions	Indicators	Measurement Scale	
Governance	Institutional capacity to coordinate actors, resources, and decision-making processes toward organizational objectives and sustainability goals	Degree of effectiveness in strategic planning, participation, transparency, accountability, and collaborative management	Strategic Governance, Participatory Governance, Administrative Governance	Transparency, Accountability, Stakeholder Participation, Strategic Planning, Institutional Coordination, Decision Effectiveness	1–5 Scale	Likert
Human Capital	Set of competencies, skills, knowledge, and experiences possessed by academic and administrative personnel	Perceived level of intellectual and professional capacities within the institution	Knowledge, Skills, Experience, Learning Capacity	Academic Qualifications, Research Productivity, Professional Development, Organizational Learning	1–5 Scale	Likert
Structural Capital	Institutional resources that support knowledge generation and organizational functioning	Availability and effectiveness of organizational structures and knowledge repositories	Organizational Structure, Knowledge Infrastructure, Institutional Memory	Policies, Procedures, Databases, Knowledge Repositories, Administrative Systems	1–5 Scale	Likert
Relational Capital	Value generated through internal and external relationships among stakeholders	Intensity and quality of collaborative networks and partnerships	Internal Relations, External Relations, Strategic Alliances	Collaboration, Trust, Partnerships, Stakeholder Engagement, Interinstitutional Cooperation	1–5 Scale	Likert
Technological Capital	Technological resources supporting organizational and academic activities	Availability and utilization of technological infrastructures and digital systems	Digital Infrastructure, Innovation Systems, Information Technologies	Information Systems, Digital Platforms, Technological Resources, Innovation Tools	1–5 Scale	Likert
Knowledge Management	Processes associated with knowledge acquisition, storage, transfer, and application	Effectiveness of institutional knowledge processes	Acquisition, Storage, Transfer, Application	Knowledge Sharing, Knowledge Retention, Knowledge Dissemination, Knowledge Utilization	1–5 Scale	Likert
Innovation	Capacity to generate new products, services,	Degree of institutional innovation performance	Scientific Innovation, Technological Innovation,	Publications, Patents, Technology Transfer, Innovative Projects	1–5 Scale	Likert

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

Variable	Conceptual Definition	Operational Definition	Dimensions	Indicators	Measurement Scale
	processes, and knowledge		Organizational Innovation		
SDG Performance	Institutional contribution to Sustainable Development Goals	Extent to which university activities support sustainability objectives	Educational Sustainability, Social Sustainability, Environmental Sustainability	Sustainable Practices, Social Impact, Community Engagement, SDG Integration	1–5 Likert Scale

Appendix B. Dimensions and Indicators

Table B1. Governance Indicators

Dimension	Indicator	Code
Strategic Governance	Strategic Planning	G1
Strategic Governance	Institutional Vision	G2
Strategic Governance	Policy Alignment	G3
Participatory Governance	Stakeholder Participation	G4
Participatory Governance	Collaborative Decision-Making	G5
Participatory Governance	Academic Involvement	G6
Administrative Governance	Transparency	G7
Administrative Governance	Accountability	G8
Administrative Governance	Institutional Coordination	G9

Table B2. Intellectual Capital Indicators

Variable	Indicator	Code
Human Capital	Academic Competencies	HC1
Human Capital	Research Productivity	HC2
Human Capital	Professional Development	HC3
Human Capital	Organizational Learning	HC4
Structural Capital	Institutional Procedures	SC1
Structural Capital	Knowledge Repositories	SC2
Structural Capital	Administrative Systems	SC3
Structural Capital	Organizational Memory	SC4
Relational Capital	Strategic Alliances	RC1
Relational Capital	Stakeholder Engagement	RC2
Relational Capital	Collaborative Networks	RC3
Relational Capital	Trust Relationships	RC4
Technological Capital	Information Systems	TC1
Technological Capital	Digital Platforms	TC2
Technological Capital	Technological Infrastructure	TC3
Technological Capital	Innovation Technologies	TC4

Appendix C. Expert Judge Evaluation Instrument

Table C1. Expert Evaluation Criteria

Criterion	Description	Scale
Clarity	Degree to which the item is understandable and unambiguous	1–5

DOI: 10.46121/pspc.54.3.08

Power System Protection and Control
ISSN:1674-3415

Criterion	Description	Scale
Relevance	Degree to which the item represents the construct	1–5
Consistency	Degree of coherence with the theoretical framework	1–5
Sufficiency	Degree to which the item adequately measures the dimension	1–5
Pertinence	Degree of alignment with research objectives	1–5

Scale:
1 = Very Poor
2 = Poor
3 = Acceptable
4 = Good
5 = Excellent

Appendix D. Expert Judge Assessment Results

Table D1. Governance Evaluation

Judge	Clarity	Relevance	Consistency	Sufficiency	Pertinence	Mean
J1	5	5	5	4	5	4.8
J2	4	5	5	5	5	4.8
J3	5	5	4	5	5	4.8
J4	5	4	5	5	5	4.8
J5	4	5	5	5	4	4.6
J6	5	5	5	5	5	5.0
J7	5	5	4	5	5	4.8

Overall Mean = 4.80

Table D2. Human Capital Evaluation

Judge	Clarity	Relevance	Consistency	Sufficiency	Pertinence	Mean
J1	5	5	4	5	5	4.8
J2	4	5	5	5	5	4.8
J3	5	5	5	4	5	4.8
J4	5	4	5	5	5	4.8
J5	5	5	5	5	4	4.8
J6	5	5	5	5	5	5.0
J7	4	5	5	5	5	4.8

Overall Mean = 4.83

Table D3. Structural Capital Evaluation

Judge	Clarity	Relevance	Consistency	Sufficiency	Pertinence	Mean
J1	5	5	5	4	5	4.8
J2	5	5	5	5	5	5.0
J3	4	5	5	5	5	4.8
J4	5	4	5	5	5	4.8
J5	5	5	4	5	5	4.8
J6	5	5	5	5	5	5.0
J7	5	5	5	4	5	4.8

Overall Mean = 4.86

DOI: 10.46121/pspc.54.3.08

Table D4. Relational Capital Evaluation

Judge	Clarity	Relevance	Consistency	Sufficiency	Pertinence	Mean
J1	5	5	5	5	5	5.0
J2	5	5	4	5	5	4.8
J3	5	5	5	5	5	5.0
J4	5	4	5	5	5	4.8
J5	5	5	5	5	4	4.8
J6	5	5	5	5	5	5.0
J7	5	5	5	5	5	5.0

Overall Mean = 4.91

Table D5. Technological Capital Evaluation

Judge	Clarity	Relevance	Consistency	Sufficiency	Pertinence	Mean
J1	5	5	4	5	5	4.8
J2	5	5	5	5	5	5.0
J3	5	4	5	5	5	4.8
J4	5	5	5	4	5	4.8
J5	5	5	5	5	4	4.8
J6	5	5	5	5	5	5.0
J7	5	5	5	5	5	5.0

Overall Mean = 4.89

Table D6. Global Expert Evaluation Summary

Variable	Mean Score	CVR	Decision
Governance	4.80	0.86	Accepted
Human Capital	4.83	0.86	Accepted
Structural Capital	4.86	0.86	Accepted
Relational Capital	4.91	1.00	Accepted
Technological Capital	4.89	1.00	Accepted
Knowledge Management	4.92	1.00	Accepted
Innovation	4.88	0.86	Accepted
SDG Performance	4.90	1.00	Accepted

The evaluation results indicate high levels of agreement among expert judges regarding the clarity, relevance, consistency, sufficiency, and pertinence of all constructs. All Content Validity Ratio values exceeded the minimum recommended threshold, supporting the adequacy of the measurement model and the subsequent Gephi network analysis.

DOI: 10.46121/pspc.54.3.08