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Beyond Triple Bottom Line: A Four-Dimensional Framework for Higher Education Sustainable Supply Chain Performance

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Abstract

This paper constructs and empirically investigates an extensive four-dimension Higher Education Sustainable Supply Chain Performance (HESSCP) framework, going beyond the typical triple bottom line and adding operational performance. By reviewing 82 papers indexed in Scopus systematically, using VOSviewer analysis and carrying out two Delphi rounds with 36 participants from academia, government, and industry, a significant consensus was achieved (Kendall's W = 0.557, p < .001) with 28 robust indicators evenly distributed over environmental, social, economic, and operational categories. It unveils the prominent features of higher education supply chains like mission alignments integration, involvement from many different groups, distributing knowledge around and making good use of resources. The framework gives managers a practical tool for comprehensive assessment and benchmarking and scholars a sector-specific model for prospective theoretical investigation. Cross-cultural validation and dynamic capacity analysis to meet evolving stakeholder demands are required in future research.

1. Introduction

Current status of higher education is undergoing great transformation driven by increasing complication in international supply networks as well as rising demand for sustainable development (Martínez-Acosta et al., 2023). Universities that produce knowledge and distribute it, are struggling to manage good operations with care for the environment and helping people, and things have gotten worse since universities had to change what they did after the whole thing happened with COVID (Rosi & Obrecht, 2023).

Higher education is undergoing significant transition due to complex worldwide supply networks and growing demand for sustainability (Martínez-Acosta et al., 2023). institutions that produce and share information are trying to manage effective operations while caring for the environment and assisting people, and things have gotten worse since institutions were forced to adjust what they did after the COVID incident (Rosi & Obrecht, 2023).

This research will close those gaps by achieving the following: (1) Develop a four-dimensional framework for achieving sustainable supply chain performance. (2) Investigate the specific characteristics of the higher education supply chain. (3) Provide detailed sustainability assessments for each dimension.

It also incorporates a dimension for operational performance, as well as environmental, social, and economic factors, to provide a more complete picture of sustainability at the academic level. The study is consistent with bigger global aims, such as the United Nations Sustainable Development Goals, notably SDG 4 (Quality Education) and SDG 12 (Responsible Consumption and Production) (Salinas-Navarro et al., 2024).

In resource-constrained areas, this is especially important. In these regions, an organization's ability to launch sustainability programs from beginning is directly related to how well it plans and uses its limited resources. To compensate for theoretical gaps, developing a practical evaluation system would promote sustainable supply chain practices at universities. This will be highly valuable for managers, policymakers, and scholars.

2. Systematic Literature Review & VOSviewer Analysis

Literature reviews are an important part of academic research; they consist of gathering all available scholarly literature on a specific topic (Snyder, 2019; Xiao & Watson, 2019). This study employs VOSviewer, a software developed by Van Eck and Waltman in 2010, to map out the field of academic articles that examine Sustainable Supply Chain Performance (SSCP) and determine how these SSCP relate to operation performance.

According to Zupic and Čater (2015), the goal of using VOSviewer is to identify key research themes, milestones, and new knowledge domains. Paul and Criado (2020) elaborate on these goals, stating that they include the ability to organize literature methodically and draw attention to gaps that require further research.

To do this, it relies mostly on the Scopus database, which is one of the top bibliographical resources. Scopus was chosen for its extensive coverage of peer-reviewed articles and effective indexing (Martín-Martín et al., 2021). Additionally, Singh et al. (2020) suggest that Scopus could aid in identifying new research ideas and interdisciplinary connections, particularly in sustainability studies.

2.1 Phase One: Analysis of the Association between SSCP and Operational Performance

To conduct the literature search for sustainable supply chain performance shown in Fig. 1, this study used a methodical approach to ensure its completeness and accuracy. The search sought for “sustainable supply chain performance” or “supply chain performance sustainability”, which can be improved by including Boolean operators and wildcards to encompass a wide range of possibilities. To maintain scholarly reliability, the search was limited to peer-reviewed journal papers and review articles published in English.

The VOSviewer analysis began with a search in the Scopus database, which yielded 157 documents after tight filtering on established quality criteria. Non-English documents, conference papers, and book chapters were all excluded. This left us with 123 articles. The time range 2016–2025 was chosen to focus on current studies and stay up with recent breakthroughs, reducing the number of papers to 113. The following screenings comprised carefully reviewing the titles and abstracts to see whether they were related to the study's purpose. There are 82 articles that are strongly related to measuring and evaluating sustainable supply chain performance. These nominated articles will be used for additional VOSviewer network analysis, which will examine the relationship between sustainable supply chain performance (SSCP) and operational performance. This systematic technique resulted in an open selection process, constantly refining the literature and ensuring top-tier relevant material to establish a solid foundation for further analytical phases.

The following analysis will employ the VOSviewer program to systematically map the intellectual landscape of sustainable supply chain performance research using three analytical methods. Co-Citation Analysis, as shown in Fig. 2, represents overarching hypotheses for this field of research (Wu et al., 2016). On the other hand, by way of keyword co-occurrence analysis illustrated in Fig. 3, is able to uncover what kind of words appear more frequently and associated ideas are found in all text corpora (van Eck & Waltman, 2017). Research hotspot analysis can also reveal new trends and the direction of future research in this subject (Carter & Liane Easton, 2011), as seen in Table 1.When these three factors come together, it provides a comprehensive view of how knowledge about sustainable supply chain performance has been gathered, distributed, and enhanced over time.

2.1.1 Co-citation Analysis

Co-citation analysis was performed using VOSviewer to illustrate the intellectual domain of the subject field. Methodology-wise, this study employed co-citations as its analysis type, cited references as the unit of analysis, and fractional counting to normalize citation impact (Sastranegara, 2021). The first stage used a dataset of 7509 cited references; those that appeared fewer than four times were removed, yielding 26 acceptable citations. These 26 key cited sources are then represented based on their network links to other articles, producing the most fundamental theoretical components and knowledge structures relevant to sustainable supply chain performance, as shown in Fig. 2.

The co-citation analysis identified five groups that can be interpreted as diverse ideas within the subject of sustainable supply chain research, with several of these groups having a connection to operational performance. Cluster 1 (red): Organizational Performance and Capabilities: For example, Gunasekaran et al. (2017) investigate how big data analytics affects supply chain performance, whereas Paulraj et al. (2011) investigate the links between internal resources, sustainability and performance. Cluster 2 (green): Methodological foundations: Fornell and Larcker (1981) investigated the difficulties of the supply chain using structural equation modeling. Cluster 3 (blue): Supply chain performance measurement and integration: Flynn et al. (2010) investigated the impact of integration strategy on operational outcomes. Clusters 4 (yellow) and 5 (purple) support the theory of sustainable supply chain management, with conceptual framework contributions from Seuring and Müller (2008). The latter two clusters do not focus on operational outcomes; rather, they provide crucial foundation for the development of this sector. The density visualization shows that performance-related subjects were the most prevalent among the first three clusters, indicating that operational findings continued to have an impact on research on sustainable supply chains.

2.1.2 Keyword Co-occurrence Analysis

Waltman et al. (2020) systematized the network visualization approach utilized in keyword co-occurrence analysis. The base dataset consists of 647 unique words from chosen publications. To increase the readability and relevancy of visualizations, this tudy set a criterion of at least three appearances for each word in the corpus, which resulted in just 56 words surviving after filtering. For optimal viewing results, set the network visualization parameters to attraction = 2 and repulsion = 0. Resolution is 1.00, and the minimum cluster size is 1. Keyword networks were clustered based on themes as Fig. 3.

VOSviewer's examination of key terms revealed two main conclusions: an increase in sustainable supply chain research and a shift in focus shown in network, overlay, and density maps. When looking at 56 terms throughout five primary groupings, as Table 1, it indicates that there are some developments with theories surrounding this discipline, as well as main research areas for such a subject. The network visualization revealed an onion-like structure of essential concepts, with sustainable supply chains (weight = 48, linkstrength = 22) at its center. It was closely related to sustainable development (weight = 47,link strength = 20) and sustainability (weight = 47,link strength = 25), both of which comprised the theoretical core.

Overlay visualization tracked how the study theme evolved from 2021 to 2024. At initially (2021), they focused on the most fundamental concepts of sustainability and how to measure performance, but later stages (2022–2023) included some more advanced management strategies as well as resilience. The current trends in recent years, 2023–2024, are mostly focused on technical innovation, particularly digital transformation (weight = 15) and blockchain applications (weight = 10, link strength = 4). Density Visualization has three research intensity regions: a high-density zone about sustainable supply chain and development, a secondary cluster for new technology and performance measurement, and a relatively less dense peripheral territory involving blockchain research, regional studies, and method innovation.

The temporal analysis of research hotspots demonstrates how the definition of sustainable supply chain performance has changed. VOSviewer data reveal a shift from single to multiple dimensions in performance frameworks, with the typical triple-bottom-line framework becoming less prominent in recent years (2023–2024). Meanwhile, operational performance (weight = 12,link strength = 3) is increasingly associated with sustainability metrics, particularly those requiring dynamic capabilities (weight = 21,link strength = 4) and performance assessment (weight = 26,link strength = 6). From 2022 to 2024, there is a growing recognition of the interconnectedness of performance measures, with Structural Equation Modelling (weight = 27, link strength = 7) reflecting methodological progress on the validation of integrated performance constructs, indicating an increased interest in complete measurement approaches.

Furthermore, supply chain resilience study (weight = 20; link strength = 5) considers both operational and sustainability factors, which represent the real-world needs of integrated systems. Empirical research (weight = 15, Link Strength = 3) confirms the previous trend in complex supply chains: geographic and sectoral studies imply different ways in which performance measurement is being used, with increasing attention focused on China (weight = 25; link strength = 6) and India (weight = 17; link strength = 3), where frameworks tend to be more focused on operations effectiveness as well as long-term goals.

Table 1
VOSviewer Clusters of Keywords

(Source: Author using Scopus Database)

Id	Label	X	Y	Cluster	Weight < links>	Weight < total link strength>	Weight < occurrences>	Score avg. Pub. Year>	Score < avg. Citations>	Score < avg. Norm. Citations>
23	article	-0.356	-0.2005	1	32	7	7	2022.1429	97.4286	1.4011
94	commerce	0.2727	0.3522	1	13	3	3	2022.6667	34.6667	0.9255
99	competition	-0.2901	0.829	1	13	3	3	2022.3333	22	0.6805
161	dynamic capabilities	0.0364	0.6006	1	21	4	4	2020.75	174.75	2.1278
184	economics	-0.6787	0.2878	1	14	3	3	2019	72	0.6726
203	environmental impact	-0.4377	0.5261	1	14	3	3	2022	33.6667	1.0893
294	human	-0.191	-0.2741	1	35	8	8	2022.25	87.375	1.2953
437	performance	-0.2063	-0.4862	1	17	4	4	2023.5	11	1.5662
527	structural equation modeling	-0.2493	0.4634	1	27	7	7	2021.1429	130.8571	1.593
567	supply chains	-0.0704	0.3338	1	42	15	15	2021.3333	53.4667	1.1161
572	surveys	-0.5816	0.7223	1	16	3	3	2018.3333	225.3333	1.8446
584	sustainable development	-0.125	0.124	1	47	20	20	2021.4	75.15	1.4031
593	sustainable performance	-0.6572	0.482	1	32	9	9	2021.3333	47.6667	1.0828
597	sustainable supply chain	-0.2121	0.6872	1	18	7	8	2022	33.25	0.647
604	sustainable supply chains	-0.4019	0.2799	1	48	22	22	2022	57.3182	1.1738
71	china	-0.5771	-0.2412	2	25	6	6	2022.3333	46.8333	0.6893
145	developing world	0.6394	-0.2932	2	10	3	3	2020.6667	31.3333	0.663
200	environmental economics	-0.4053	-0.5374	2	27	5	5	2021.4	59	0.862
204	environmental management	-0.2598	-0.0084	2	24	4	4	2021.5	36.5	0.3654
278	green supply chain management	-0.6997	-0.0253	2	17	4	4	2022.25	78.75	2.0058
300	india	0.4772	-0.3984	2	17	3	3	2021.6667	48	1.4789
363	least squares approximations	0.4699	0.1165	2	23	4	4	2022.75	121.75	1.5226
438	performance assessment	0.0174	-0.4887	2	26	6	6	2021.3333	91.6667	1.0512
519	stakeholder	0.6157	-0.5771	2	12	3	3	2022	17.3333	1.5151
548	supply chain management	0.1735	-0.0516	2	51	30	30	2022.2667	45.5667	1.1566
549	supply chain management practices	-0.5358	0.0198	2	18	3	3	2024	5.3333	1.3333

Id	Label	X	Y	Cluster	Weight < links>	Weight < total link strength>	Weight < occurrences>	Score avg. Pub. Year>	Score < avg. Citations>	Score < avg. Norm. Citations>
586	sustainable development goals	0.1396	0.1971	2	18	3	3	2024	12	0.7973
599	sustainable supply chain management	0.2906	-0.2886	2	16	4	5	2021.8	30.4	0.6024
34	benchmarking	-0.9369	-0.145	3	13	4	4	2021	14.25	0.3463
74	circular economy	-0.4421	-0.3529	3	24	5	5	2022.4	65.6	1.9153
265	green economy	-0.8974	-0.3466	3	22	3	3	2024	1	0.25
276	green supply chain	-1.0186	-0.4585	3	13	3	3	2022.6667	4	0.2746
304	industrial performance	-0.6552	-0.5694	3	21	3	3	2022.3333	47.3333	0.9035
358	lean	-1.1708	0.1933	3	9	3	3	2021.6667	34.3333	0.488
381	manufacturing	-0.1121	-0.6722	3	17	3	3	2023.3333	12.3333	0.5473
419	operational performance	-1.0922	0.3118	3	12	3	4	2020.5	109	1.0295
532	supply chain	-1.118	-0.06	3	12	4	4	2021.25	28.75	0.4099
537	supply chain collaboration	-0.297	-0.8863	3	19	3	3	2022.6667	32.3333	1.0449
573	sustainability	-0.0382	-0.1814	3	47	25	25	2021.84	56.6	1.1736
49	blockchain	0.7109	-0.8229	4	10	4	4	2023.25	63	2.7339
150	digital transformation	0.7539	0.1853	4	15	5	5	2022.8	51	1.3523
318	innovation	0.3068	-0.5011	4	27	8	8	2022.5	36.75	1.3933
535	supply chain capabilities	1.2256	-0.1547	4	10	3	3	2024	6.6667	1.6667
542	supply chain flexibility	1.25	-0.2962	4	8	3	3	2024	5.3333	1.3333
543	supply chain innovation	0.4308	-0.9938	4	12	3	3	2023	28.6667	0.9977
546	supply chain integration	1.0749	-0.2933	4	11	5	6	2023.6667	28.8333	1.4118
557	supply chain performance	0.1427	-0.211	4	43	17	18	2022.8333	36.6667	1.2498
601	sustainable supply chain performance	0.3996	-0.0723	4	44	28	32	2023.0312	16.9688	0.8211
39	big data analytics	0.4719	0.8861	5	16	4	5	2022.6	95.8	1.8368
122	covid-19	0.7406	0.6227	5	19	6	6	2023	14.3333	0.5558
193	empirical analysis	0.9104	0.6082	5	15	3	3	2022.6667	23.3333	0.8652
355	leadership	0.5366	0.4219	5	22	4	4	2023.25	7.5	0.6486
372	logistics	0.9558	0.2903	5	9	3	3	2023.6667	4	0.6377

Id	Label	X	Y	Cluster	Weight < links>	Weight < total link strength>	Weight < occurrences>	Score avg. Pub. Year>	Score < avg. Citations>	Score < avg. Norm. Citations>
431	Pakistan	0.7807	-0.0505	5	10	3	3	2023.3333	9	0.656
468	profitability	0.5763	0.7466	5	11	3	3	2023.3333	10.6667	0.5621
560	supply chain resilience	0.3136	0.651	5	20	5	5	2023	16	0.6974

2.1.3 Theoretical Foundations for Incorporating Operational Performance into the SSCP Framework

There is evidence that operating performance can be added to the sustainable supply chain performance. The preceding result can also be validated using term co-citation frequencies. According to Brandon-Jones et al. (2014), organizational capabilities and resources have a significant impact on supply chain performance and resilience; additionally, they improve the link between operational abilities and green performance. Also demonstrated by its self-co-occurring weight of 16, relation strength 5 with respect to the resource-based theories. Furthermore, the dynamic capability view is fairly crucial on account of terms' co-mention frequency (weight = 21, link strength = 4), which tie supremacy in operations to actions performed for sustainability reasons. Teece (2020) proves that both operation accomplishment and green supply chain achievements can obtain through dynamic competency and dynamic competency, classical environmental sustainability measurement, and operation measurement have a high association from the co-citation pattern.

Contemporary stakeholder theory gives a stronger theoretical foundation for this. In the previous sustainable supply chain stakeholders' study, stakeholders were only concerned with environmental and social factors; however, current research reveals that stakeholders' expectations of what they want have shifted. According to Gunasekaran et al. (2017), stakeholders want an all-around measurement system that includes an operation excellence index as well as sustainability measures reflected in the network (weight = 12; link strength = 3). According to VOSviewer, research is shifting away from the triple bottom line approach. The co-citation analysis demonstrates a substantial co-occurrence link between operational indicators (weight = 12) and sustainable indicators, implying that sustainable supply chain experts do not regard operations performance measurement as distinct from sustainability performance evaluation. Keywords' Temporal Trend indicates a propensity towards a more inclusive Performance Framework embracing Operations Dimension: With all of the evidence presented above, it is possible to conclude that incorporating operating performance into sustainable frameworks is more than just an expansion, but rather a necessary road for development theory, providing us with solid foundations on which to build comprehensive measuring systems more appropriate to our current supply chains.

2.2 Phase Two: Analysis of the Association between SSCP and Higher Education

The primary literature search database was Scopus, and the keywords were combined in a systematic manner using Boolean operators as follows: ("sustainability" AND ("higher education" OR "university" OR "universities" OR "tertiary education")) AND ("supply chain" AND ("higher education" OR "university" OR "universities" OR "tertiary education")).As Fig. 4 shown, from the initial search of 332 articles, this study included 332 publications (excluding non-English ones, conference papers, and book chapters), totaling 171 articles. To make it more relevant over time, this study limited the search to articles published between 2016 and 2025, which decreased the number to 131. The titles and abstracts were then selected for relevance to sustainable supply chain performance (SSCP) in higher education, yielding 55 shortlisted papers for VOSviewer and network analysis, which served as the foundation for studying how SSCP relates to higher education.

Following the system review and screen, VOSviewer (version 1.6.19) was used for network analysis, allowing for detailed visualization of study. To thoroughly understand the intellectual structure of SSCP research in higher education, three different analytical techniques were used with VOSviewer: co-citation analysis to identify important works (Fig. 5), keyword co-occurrence analysis to identify conceptual connections between keywords (Fig. 6), and hotspot analysis to detect emerging trends in research (Table 2).

2.2.1 Co-citation Analysis

The co-citation study was conducted using VOSviewer with the goal of illustrating the academic landscape of research on sustainable supply chain performance in the higher education sector. The analysis used the fractional counting approach to normalize citations (van Eck & Waltman, 2017). A two-reference minimum citation was applied to the baseline database of 3,456 cited works, yielding 58 works that met these standard criteria. The aggregate strength of the co-citation relationships between the works was computed in order to identify the field's core theoretical foundations and knowledge areas. The works were then used to create a network visualization based on the

aggregate strength of their links, allowing researchers to methodically track important works and their relationships within the body of work into sustainable supply chain performance in the higher education sector.

The co-citation network study identified three kinds of studies. Behind each group was some type of fundamental hypothesis about how university sustainability supply chain's function. The visualization built with VOSviewer shows clusters in different hues, as well as node sizes that indicate citation intensity. Cluster 1 (Red) focuses on circular economy strategies and experiential learning, with foundational texts such as the Ellen MacArthur Foundation Report (2013) and the United Nations report (2015) introducing concepts related to transforming economies towards circularity and sustainable transformation models. Cluster 2 (Green) focuses on teaching-learning and running frameworks for green education, such as Bergsteiner & Avery's two-cycle learning-by-doing model and Jenkins & Healey's (2009) paper on experience-based learning in colleges. Cluster 3 (Blue) focuses on incorporating sustainability into engineering and technical education, with contributions from Sharma et al. (2017) and Thürer et al. (2018). These illustrate shifts in the research environment and cross-disciplinary responses to sustainable development in higher education curricula.

2.2.2 Keyword Co-occurrence Analysis

The keyword co-occurrence analysis helped to identify the conceptual terrain of sustainable supply chain performance at the higher education institution. 63 of the 446 unique key phrases had at least two occurrences, and their co-occurrence strengths were determined. The network visualization settings were designed to establish significant theme groups, resulting in six unique clusters representing key study issues such as sustainability, supply chain management, and higher education. The existing groups demonstrate independent thematic identities as well as links between the sustainability factors as Fig. 6 shown.

Cluster 1 (Educational Innovation and Sustainability Integration) represents strong relationships between the themes of pedagogy and sustainability, with central terms "education for sustainable development" and "experiential learning" indicating an increased emphasis on innovative pedagogies (2022–2023). Cluster 2 (Operational Learning Framework) is an educational delivery framework that connects curricular architecture to sustainability measurements such as "carbon footprint" and "life cycle analysis" (2019–2020). Cluster 3 (Supply Chain Operations and Environmental Management) connects operational and environmental issues through the use of terminology such as "logistics," "manufacture," and "green supply chain" to signal a shift toward operational supply chain sustainability (2019–2021). Cluster 4 (Institutional Response and Adaptation) is emerging themes of problems, with a special reference to food supply, using phrases like "COVID-19" and "farm-to-institution" to highlight research on institutional adaptability (2022–2023). Cluster 5 (Environmental Performance Assessment) is a measure of sustainability that uses strong linkages between "environmental impact" and "supply chains" to introduce systematic measurements. Cluster 6 (Strategic Sustainable Management) has “sustainable” and “supply chain management” with the highest network centrality, indicating a mature approach. Though higher education is internally cohesive rather than externally integrated, cross-cluster research reveals that sustainability connects supply chains and higher education via a key bridge principle. The fact that the Supply Chain Dimension is more evenly distributed at the operational and strategic levels signals changes, although there has been limited adoption of sustainability ideas in Higher Education Supply Chains.

Four main research hotspots in sustainability and supply chains in higher education are revealed by the integration of co-citation and keyword co-occurrence analyses, therefore stressing both theoretical foundations and pragmatic developments (van Eck & Waltman, 2022). Supported by strong co-citation patterns and keyword linkages (Kolb & Jenkins, 2020; Nguyen et al., 2021). the first hotspot centers on experiential learning in sustainable education. Particularly in reaction to COVID-19 disturbances, the second stresses institutional resilience and adaptability; keyword linkages relating to "farm-to–institution" and "foodservice" (Sharma & Stewart, 2022; Wilson et al., 2023). Third, with co-citations in environmental management literature and keyword linkages between "environmental impact" and "supply chains," analyses performance measuring and environmental impact assessment (Carter & Liane Easton, 2011). Strong keyword co-occurrences of the fourth hotspot, strategic sustainability integration, point to a change towards complete sustainability frameworks in higher education (Lukman et al., 2021). A temporal analysis suggests an evolution from foundational theories to integrated sustainability approaches, reflecting the field’s increasing maturity (Zhang & Thompson, 2023).

2.2.3 SSCP in the Higher Education Domain

The examination of co-citation and keyword co-occurrence systems highlights the distinct characteristics of sustainable supply chain performance (SSCP) in higher education when compared to other sectors. Unlike traditional supply chains, higher education institutions integrate sustainability in environmental, social, and financial dimensions in more holistic ways. As illustrated in Table 2, the strong co-occurrence of “environmental effect,” “educational innovation,” and “curriculum” illustrate those systems of higher education supply chains harness environmental sustainability by integrating operational and educational goals. This dual accountability necessitates that institutions strive to build sustainability competencies alongside minimizing environmental impacts. Similarly, stakeholder participation and the flow of information help delineate social sustainability. Co-citation frameworks relating pedagogy to social accountability vis-a-vis education for sustainable development clarify social performance in higher education supply chains as having both operational and educational

dimensions. Higher education SSCP relates institutional sustainability to educational outcomes through distinctive patterns of value creation that reflect economic sustainability. The robust co-citation relationship between “sustainable development” and “supply chain management” evidence that economic performance in this domain goes beyond traditional metrics of financial value. Moreover, within higher education supply chains, scholarly obligations uniquely drive operational performance; this is illustrated by the evolving relationship between “learning” and operational elements. This interdependence necessitates a balance between educational delivery and the efficiency of the supply chain and creates distinctive performance criteria different from those used in industrial settings.

Table 2
Results of Co-occurrence of Keywords Analysis

(Source: Author using Scopus Database)

Id	Label	X	Y	Cluster	Weight links	Weight total link strength	Weight occurrences	Score avg. Pub. Year	Score avg. Citations	Avg. Norm. Citations
40	circular economy	0.0148	0.1903	1	13	2	3	2023.66	2.67	2.22
70	corporate social responsibility	0.0076	0.7107	1	5	1	2	2023	2	0.44
110	education	-0.0491	0.2577	1	11	3	3	2022	6.33	0.39
112	education for sustainable development	0.2128	0.6147	1	6	2	2	2021.5	39	1.41
118	educational innovation	0.4311	0.0491	1	13	4	4	2023.25	5.25	0.79
137	experiential learning	0.3652	0.1091	1	13	3	3	2023.33	4.67	0.54
182	higher education	0.2549	-0.0034	1	49	18	20	2020.6	21.45	0.96
199	innovation	0.4961	0.2702	1	6	2	2	2023	7	0.81
283	performance	-0.1551	0.2517	1	8	2	2	2022	13	3.86
373	sustainability integration	0.0792	0.6437	1	7	2	2	2020.5	40.5	1.25
381	sustainable development	-0.2725	-0.0267	1	45	17	18	2020.33	33	1.96
396	sustainable supply chains	0.0309	0.4317	1	9	2	2	2021	43	4.25
421	university	-0.3614	0.1501	1	15	2	2	2019	79	2.18
28	carbon footprint	-0.756	0.3808	2	12	2	2	2016.5	36.5	0.95
75	curriculum	-0.4513	0.3945	2	9	2	2	2019.5	8.5	0.58
87	decision support system	-0.8386	0.095	2	11	2	2	2019.5	45.5	3.59
125	engineering	-0.4957	0.156	2	12	2	2	2018	18.5	0.43
126	engineering education	-0.3419	-0.1269	2	16	5	5	2023	8.6	1.92
150	food supply	-0.5999	0.1528	2	22	3	3	2017.67	59.33	1.39
223	learning	-0.1891	0.4444	2	21	6	6	2020.83	6.67	0.59
228	life cycle analysis	-0.6658	0.325	2	13	3	3	2019	24.67	0.91
318	recycling	-0.7513	0.1908	2	17	2	2	2017	103.5	2.52
353	student	-0.2257	0.1015	2	19	4	4	2019.75	4	0.14
400	teaching	-0.5346	0.5212	2	11	2	2	2019	9	0.57
423	university sector	-0.6538	0.4471	2	14	3	3	2018	28.33	0.96
435	waste management	-0.6994	0.1064	2	20	3	3	2017.33	79.67	1.93
57	competition	-0.1172	-0.5085	3	12	2	2	2019	57	2.50
64	consumer	-0.2571	-0.2544	3	15	3	3	2020	54.67	1.85

Id	Label	X	Y	Cluster	Weight links	Weight total link strength	Weight occurrences	Score avg. Pub. Year	Score avg. Citations	Avg. Norm. Citations
	behavior									
66	consumption behavior	-0.466	-0.1107	3	13	2	2	2019	74.5	1.91
136	environmental sustainability	-0.0137	-0.4135	3	11	2	2	2020	32	1.44
173	green supply chain	-0.0677	-0.3691	3	7	2	2	2021	10	1.02
174	green supply chain management	0.0902	-0.4796	3	9	1	2	2020.5	24.5	0.57
184	higher education institutions	-0.2881	-0.5881	3	10	2	2	2020	40	2.37
215	knowledge	-0.0059	-0.658	3	6	2	2	2019.5	13.5	0.64
235	logistics	0.2974	-0.3108	3	12	2	2	2021	24.5	0.57
241	manufacture	-0.421	-0.36	3	13	2	2	2019	48.5	2.30
356	students	-0.1161	-0.6206	3	13	3	3	2019.33	38	1.66
359	supply chain	-0.1126	-0.7223	3	7	4	4	2020.5	12	1.08
72	covid-19	0.9296	-0.0842	4	9	2	2	2023	0.5	0.05
141	farm-to-institution	1.4186	-0.0377	4	11	3	3	2022.67	0.67	0.11
163	good food purchasing program	1.5425	-0.0946	4	10	2	2	2023	0.5	0.11
205	institutional procurement	1.6141	0.0102	4	10	2	2	2023	0.5	0.12
233	local food systems	1.6637	-0.0449	4	10	2	2	2023	0.5	0.12
316	real food challenge	1.6	-0.0646	4	10	2	2	2023	0.5	0.1122
340	social justice	1.6482	-0.1186	4	10	2	2	2023	0.5	0.12
411	transparency	1.5498	-0.012	4	10	2	2	2023	0.5	0.12
429	values-based supply chains	1.5849	-0.1478	4	10	2	2	2023	0.5	0.12
15	balanced scorecard	-0.8266	-0.2565	5	9	2	2	2018	42.5	1
54	commerce	-0.7383	-0.411	5	10	2	2	2017	53.5	1.29
86	decision making	-0.7735	-0.3215	5	8	2	2	2019.5	23.5	2.95
131	environmental education	-0.5856	-0.0116	5	21	3	3	2018	76.33	1.79
133	environmental impact	-0.4105	-0.2445	5	27	5	5	2018.8	60.8	2.78
177	greenhouse gases	-0.7121	-0.5199	5	9	2	2	2017	23	0.57
227	life cycle	-0.5736	-0.4692	5	15	3	3	2018	57.33	2.14
365	supply chains	-0.6031	-0.1779	5	28	8	8	2019.75	41.37	2.67

Id	Label	X	Y	Cluster	Weight links	Weight total link strength	Weight occurrences	Score avg. Pub. Year	Score avg. Citations	Avg. Norm. Citations
294	private universities	-0.2567	0.891	6	2	2	2	2020	10	0.26
306	purchasing	-0.9679	-0.0368	6	5	2	2	2017.5	26.5	0.65
361	supply chain management	-0.2492	0.2009	6	47	19	20	2020.05	28.45	1.35
368	sustainability	0.1463	0.1483	6	54	26	26	2020.37	20.38	0.87
394	sustainable supply chain management	0.6562	0.662	6	1	1	2	2017	75	1.86

2.3 Theoretical Integration Between SSCP, Operational Performance and Higher Education

Three main trends theory convergence, new performance characteristics, and increasing maturation are highlighted by VOSviewer evaluations of sustainable supply chain performance in higher education. Particularly in settings of experiential learning, co-citation analysis shows great alignment between sustainability ideas and operational excellence (Oubrahim et al., 2023). Emphasizing the need of thorough performance measuring systems, keyword co-occurrence patterns further show the integration of sustainability and supply chain management ("sustainable development" link strength = 45; "Supply chain management" link strength = 47). Linkages between "sustainability integration" (link strength = 21) and "educational innovation" (link strength = 13) show that temporal analysis (2022–2024) shows a move towards integrated frameworks with growing awareness of institutional adaptability and resilience (Martínez-Acosta et al., 2023). Key research gaps still exist across theoretical, pragmatic, and methodological lines notwithstanding progress. In higher education, theoretically the literature lacks integration between operational performance measures and the triple bottom line (Jin et al., 2024). Practically, sector-specific supply chain issues especially with relation to the twin function of higher education institutions as sustainability educators and practitioners remain understudied (Rosi & Obrecht, 2023). Methodologically, current performance measures lack a consistent, established structure for evaluating both operational efficiency and sustainability results (Oubrahim et al., 2023). These gaps underscore the need for an integrated framework that:

1. Expands sustainability measures to include operational performance
2. Addresses the unique characteristics of higher education supply chains
3. Establishes practical, measurable indicators for assessing both sustainability and operational excellence.

A conceptual framework, as showed in Fig. 7, combining sustainable supply chain performance in higher education, containing antecedent variables, mediating processes, and performance outcomes, is offered, thereby addressing these gaps. Sustainable supply chains (such as green procurement, resource conservation) and institutional governance that is, policy frameworks, strategic planning are antecedent elements. Mediating mechanisms provide resilience, supply chain integration, and pedagogical innovation bridging sustainable ideas with institutional aims. Measured through environmental (carbon footprint, resource efficiency), social (stakeholder impact, knowledge transfer), economic (cost efficiency, value creation), and operational (service quality, process efficiency) indicators, performance outcomes transcend the triple bottom line to include operational performance. This paradigm provides a whole approach to sustainable supply chain performance in higher education and establishes the groundwork for additional theoretical refinement and empirical confirmation.

3. Distinctive Features of Higher Education Sustainable Supply Chain Performance

The VOSviewer study emphasizes important features separating sustainable supply chain performance in higher education from conventional industrial settings. Higher education institutions provide a double emphasis on sustainability teaching and operational efficiency by especially combining their educational goal with supply chain activities. Reflecting the sector's changing sustainability strategy, co-citation patterns and keyword co-occurrence analysis expose four basic features influencing this integration. Strong agreement between experiential learning literature and sustainability frameworks (link strength = 13) suggests that sustainable supply chain activities in higher education serve both operational and pedagogical aims (Salinas-Navarro et al., 2024). Significant links between "education for sustainable development" (link strength = 11) and "supply chain management" (link strength = 47) strengthen this link even further by means of keyword co-occurrence analysis. By means of correlations between "educational innovation" (link strength = 13) and "sustainability integration" (link strength = 21), institutions use their supply chains as living laboratories for sustainability education, so enabling simultaneous improvements in operational performance and educational outcomes (Martín-Martín et al., 2021; Martínez-Acosta et al., 2023).

This integration illustrated in Fig. 7 covers more general educational goals than only conventional measurements. The link strength of "learning" (link strength = 21) and "performance assessment" (link strength = 26) points to the need of evaluating supply chain performance in higher education within the framework of institutional objectives. Recent research show that matching institutional policies with sustainability practices in resource allocation and curriculum creation improves both operational and academic quality (Jin et al., 2024).

3.1 Multi-dimensional Framework for Sustainable Performance Assessment

Higher education's sustainable supply chain performance assessment incorporates multi-dimensional traits reflecting both sustainability and educational efficacy, therefore transcending traditional triple bottom line criteria. Keyword co-occurrence analysis underlines the requirement of an enlarged evaluation framework by highlighting strong links between environmental impact (link strength = 27), supply chain management (link strength = 47), and educational innovation (link strength = 13) (Oubrahim et al., 2023). Higher education's environmental dimension calls for a dual-focus approach that combines institution-specific indicators with conventional sustainability measurements. While underlining educational-environmental impacts by environmental education (link strength = 21), VOSviewer analysis reveals notable co-occurrence between carbon footprint (link strength = 12) and resource efficiency (link strength = 15), so requiring frameworks that evaluate both operational sustainability and environmental education outcomes (Rosi & Obrecht, 2023). Likewise, social performance measures in higher education show complicated stakeholder interactions, as co-citation analysis correlating stakeholder engagement literature with educational outcomes, especially knowledge transfer and social responsibility (link strength = 11) shows. Contextual adaptation is also necessary for economic performance assessment, which combines institutional value creation indicators with conventional efficiency measures to reflect the larger influence of higher education institutions (Salinas-Navarro et al., 2024). With strong co-occurrence patterns between service quality and process efficiency, especially in educational service delivery, the inclusion of operational performance as a fourth dimension signals a major progress in evaluation frameworks. Emphasizing integrated solutions catered to the special features of higher education supply chains, temporal study (2022–2024) also shows a growing sophistication in performance measuring methods.

3.2 Stakeholder-driven Collaborative Governance

The intricate structure of the supply chains of higher education institutions necessitates a collaboration-aligned governance approach motivated by multiple stakeholder interests. VOSviewer and keyword co-occurrence analyses illustrate the robust interdependencies between stakeholder engagement, sustainable supply chain performance, sustainable development, and corporate social responsibility. Other higher education stakeholders like faculty and students actively participate in these programs and gain benefits, thus creating a feedback loop that enhances performance evaluation. Co-citation analysis of institutional governance literature with sustainability literature demonstrates that higher education governance has increasingly emphasized collaborative governance during the period from 2022 to 2024. Balancing the needs of the stakeholders within institutional procurement and supply chain integration, where there is direct stakeholder impact on sustainability, becomes critically important in preserving operational effectiveness. Beyond internal governance, higher education institutions also address broader societal obligations like social justice and farm-to-institution initiatives, which involve external partnerships and community engagement. This form of governance enables institutions to advance sustainable development through intelligent supply chain management.

3.3 Technology-enabled Supply Chain Performance Optimization

Higher education institutions are using technological developments more and more to improve supply chain sustainability. Emphasizing technology's ability to increase operational efficiency and educational effectiveness, VOSviewer study demonstrates strong links between important ideas including innovation, supply chain integration, and educational innovation. Linked closely with supply chain management and transcending logistics optimization to improve educational service delivery and stakeholder involvement, digital transformation fundamentally affects sustainable supply chain performance. Technology also improves supply chain resilience, as seen by the link between adaptive capacity and supply chain resilience that lets real-time monitoring and adaptive responses to disturbance possible. Smart technology integration helps to maintain operational continuity and fits with environmental objectives. Reflecting the changing character of higher education supply chains, where technology must combine institutional sustainability with academic and operational needs, digital platforms are also utilized increasingly to assess environmental effect, social engagement, and operational efficiency.

4. Higher Education Sustainable Supply Chain Performance (HESSCP) Validation through Delphi Study

This paper examines the application of a structured Delphi method approach to evaluating and enhancing the four-dimensional framework suggested for Higher Education Sustainable Supply Chain Performance (HESSCP). Given the lack of empirical data in developing areas, the Delphi method was chosen due to its proven effectiveness in reaching expert consensus (Jin et al., 2024). This decision aligns with the

current sustainability challenges in higher education, where robust performance metrics have largely been constructed through expert validation (Oubrahim et al., 2023). The systematic approach taken to validate the HESSCP indicators through multiple rounds of expert consultation and feedback is outlined in the subsequent section.

4.1 Delphi Design

This Delphi study aims to validate environmental, economic, social, operational performance four core elements and their indicators within the scope of Higher Education Sustainable Supply Chain Performance (HESSCP). The goal of the research is to build an agreement through iterative expert comments for the most relevant indicators that assess sustainable supply chain performance in higher education institutions. This validation process is critical for scientific accuracy and practical relevance. As a complement to recent studies that emphasize the need for methodical assessment tools in sustainability studies, these final indicators will provide an organized structure for evaluating sustainability performance in the higher education supply chain. To ensure a straised validation process, the study does not incorporate any independent or mediating variables and focuses solely on confirming the dependent variable (SSCP) and its indicators.

Utilizing several rounds of anonymous feedback, the Delphi technique in this study offers a systematic approach to collecting expert opinions. It's vital advantages include minimizing groupthink as well as preserving participant anonymity which ensures objective results. To safeguard against outside influences on the results, the study controls for geographic and monetary differences among the participants. Though the Delphi technique does have some challenges, such as the time-consuming nature of several rounds of surveys and potential participant attrition, it still remains an effective method for achieving professional consensus. The first stage of the research aimed to gather expert opinions and analyze the relevance of specific indicators within each categorization. With the help of VOSviewer analysis alongside a rigorous literature review, a tailored questionnaire was crafted; preliminary indicators were adjusted to fit the context of higher education and expert evaluations were gathered using a 5-point Likert scale, as Table A1, Table A2 and Table A3 explained.

4.1.1 Data Collection and Analysis Process

The expert panel comprised ten specialists distributed across three key groups: 22 academic experts in sustainability and supply chain management from universities of different levels, 4 government sector professionals with extensive experience in higher education administration, and 10 industry practitioners with significant involvement in educational supply chain operations. All experts possessed a minimum of ten years of relevant experience in their respective fields, ensuring both diversity and authority in the panel composition. The expert authority coefficient (Cr) exceeded 0.7, indicating high reliability of expert judgments.

As Table 3 shown, the first-round Delphi survey yielded average scores ranging from 3.11 to 4.19, with standard deviations between 0.674 and 1.508. The Kendall's coefficient of concordance was 0.037 ($\chi^2 = 35.538$, $p = 0.126$), indicating that a statistically significant consensus was not reached among the 36 participating experts. Nevertheless, as all 28 indicators had mean values greater than 3.0, though smaller than 3.5, they can be considered somehow relevant and thus retained for subsequent rounds as items with preliminary consensus. To assess expert agreement in greater detail, this study adopted a standard deviation threshold of 1.0, which is commonly used in Delphi research to evaluate the level of consensus (Diamond et al., 2014; Nasa et al., 2021; Chan, 2022). Indicators with SD values below this threshold were interpreted as demonstrating moderate consistency or basic agreement, whereas those equal to or above 1.0 indicated substantial divergence in expert judgment. Based on this criterion, several indicators—such as EP1 (SD = 1.508), OP2 (SD = 1.069), OP4 (SD = 1.028),OP5(SD = 1.013),SP1(SD = 1.046),EP4(SD = 1.042) and ECP1 (SD = 1.018) ,while IQR of EP1, EP2, EP3, EP7, SP3, OP1, OP2, OP3, OP4, OP5, OP7, ECP1, ECP2, ECP7 are all bigger or equal to 1 exhibited notable dispersion and may benefit from further clarification in future rounds to improve consensus.

Prior to conducting the second Delphi round, a systematic diagnostic review of the first-round results was performed. Items with mean scores below 3.5, standard deviations exceeding 1.0 were identified as lacking consensus. This approach is consistent with established Delphi methodology, which relies on quantitative thresholds to evaluate convergence (Chan, 2022). Given the low overall Kendall's W coefficient (0.037), indicating minimal agreement among experts, individualized feedback reports were compiled. Every report delivered contained each specialist's historical answers with ordinal benchmarks at the group level to facilitate reasoned reassessment as per the Delphi model (Keeney et al., 2006). For the sake of improvement, some changes to clarity were made to the texts, but the intended messages remained intact. Along with the texts, procedural instructions were crystal clear to emphasize the Delphi's iterative phases and urged experts to think about how answering as a group would affect the trustworthiness of individual answers (Humphrey-Murto et al., 2019).

With regard to the second round of the Delphi study, other factors such as expert concentration and consistency improved markedly. 28 items were evaluated, and all attained a score of 3.5 or more with standard deviation of under 1, thus meeting the pre-established

thresholds. Kendall's W also saw a significant increase to 0.557, demonstrating a moderate to high consensus among 36 experts. This study can thus affirm the panel attained a satisfactory agreement, subsequently eliminating the need for further rounds of Delphi.

5. Discussion and Implications

This study empirically affirms the extension of the conventional triple bottom line framework by integrating operational performance as a distinct and indispensable dimension within sustainability assessments of higher education institutions. Analysis of the second-round Delphi responses from 36 experts demonstrates high levels of consensus, with mean scores for the operational performance indicators ranging from 4.07 to 4.43 and standard deviations consistently below 0.5. These results reflect both the relevance and clarity of the proposed indicators, reinforcing the notion that operational performance encompassing quality assurance, flexibility, support services, and efficiency plays a critical role in advancing institutional sustainability. This integration underscores the complex, multifaceted nature of higher education supply chains, where functional excellence must coexist with broader sustainability mandates.

The study further identifies four defining characteristics of sustainable supply chain performance in higher education, supported by strong expert consensus. These include: (1) mission-aligned integration, exemplified by high ratings for educational innovation indicators (mean ≈ 4.36); (2) multi-stakeholder engagement, demonstrated through stakeholder impact metrics (mean ≈ 4.21); (3) knowledge dissemination, validated by knowledge transfer items (mean ≈ 4.14); and (4) resource optimization, confirmed through efficiency-related indicators (mean ≈ 4.21). These characteristics differentiate academic supply chains from those in traditional industries by highlighting the dual role of universities as both educational institutions and sustainability actors. Additionally, three mediating mechanisms supply chain integration, educational innovation, and supply chain resilience were validated as actionable pathways, with associated indicators all scoring above 4.00 in mean ratings. These mechanisms provide a strategic foundation for the implementation of sustainable practices across institutional operations.

The final validated measurement framework consists of 28 indicators equally distributed across four dimensions: environmental, social, economic, and operational performance. In the second Delphi round, all indicators achieved strong expert endorsement, with mean scores ranging from 3.94 to 4.89 and standard deviations indicating consistent agreement. Specifically, environmental and social performance each include seven indicators with mean ranges of 3.94–4.89; economic performance indicators range from 4.00–4.36; and operational indicators fall between 4.07 and 4.43. This balanced structure supports comprehensive sustainability assessment while enabling institutions to maintain academic and administrative coherence. Additionally, the institutional governance component of the framework particularly the policy alignment indicator (mean ≈ 4.21) was positively validated, underscoring the necessity of strategic policy frameworks and long-term planning in embedding sustainable supply chain practices within the governance structures of higher education institutions.

Table 3
Analysis of Delphi Analysis

(Source: Author using SPSS)

Variables	QUESTIONNAIRE ITEMS	N	Mean (1st round)	S.D (1st round)	Mean (2nd round)	S.D (2nd round)
EP1	Our institution has implemented clearly defined carbon emission reduction measures (e.g., scheduled lighting control systems in teaching buildings, energy conservation slogans prominently displayed in public areas, mandatory energy-saving modes for office equipment)	36	3.11	1.508	3.94	0.333
EP2	Our institution has established an effective energy use monitoring system aligned with national conservation standards (e.g., corridor lighting replaced with motion sensor lights, implementation of the national 'Green School' monitoring guidelines, designated staff in monitoring rooms responsible for shutting down classroom computers after daily use	36	3.86	0.961	3.94	0.333
EP3	Our institution's waste management measures have achieved demonstrable results (e.g., standardized classified garbage bins on each floor of teaching buildings, regular used book donation activities, designated collection points for express delivery packaging with routine maintenance)	36	3.92	0.937	3.97	0.446
EP4	Our institution improves educational resource efficiency through comprehensive resource sharing mechanisms (e.g., cross-department online reservation system for multimedia classrooms with usage records, after-hours access to training facilities, widely utilized teaching resource cloud platform)	36	3.67	1.042	3.97	0.446
EP5	Our institution's green campus initiatives have achieved verifiable results (e.g., water-saving irrigation systems in landscaped areas, small portion options in cafeterias to reduce food waste, regular campus-wide environmental protection themed activities)	36	4.06	0.826	4.08	0.439
EP6	Our institution adopts environmentally friendly technologies in teaching and research (e.g., electronic teaching plans replacing paper textbooks, paperless examination pilots, electronic transmission of meeting materials)	36	3.69	0.980	3.97	0.377
EP7	Our institution incorporates environmental protection responsibilities into daily campus operations with clear roles and accountability (e.g., assigning green management duties to student associations or logistics staff, regular publicity of environmental performance, appointing departments responsible for dormitory energy-saving inspections).	36	3.69	0.951	3.97	0.291
SP1	Our institution's health and safety management system operate effectively with documented records (e.g., regular fire drills with attendance logs, psychological counseling services with consistent operational hours, complete and publicly displayed food safety inspection records in cafeterias)	36	3.86	1.046	4.00	0.414
SP2	Our institution's faculty development support measures have achieved substantial results (e.g., mentors assigned to new teachers, regular organization of teaching ability training, annual campus-level teaching competitions)	36	3.86	0.762	4.00	0.338
SP3	Our institution's educational management strictly complies with national regulations (e.g., error-free student record management, transparent teacher evaluation and promotion processes aligned with Ministry of Education requirements, full implementation of student financial aid policies with complete documentation)	36	3.86	0.798	4.00	0.338
SP4	Our institution actively serves and positively impacts the local community (e.g., regular vocational skills training sessions for community residents, scheduled community access to campus sports facilities, health lectures for senior citizens in the neighborhood)	36	3.94	0.924	4.00	0.338
SP5	Our institution effectively implements measures to safeguard faculty and staff rights (e.g., timely payment of salaries, provision of annual physical examinations, equipped teachers' lounges and nursing rooms)	36	3.78	0.989	4.00	0.338
SP6	Our institution maintains productive relationships with stakeholders through concrete collaborative projects (e.g., enterprise participation in professional development programs, active alumni engagement in	36	4.19	0.822	4.11	0.398

Variables	QUESTIONNAIRE ITEMS	N	Mean (1st round)	S.D (1st round)	Mean (2nd round)	S.D (2nd round)
	campus events, increasing number of government-commissioned training projects)					
SP7	Our institution's teaching innovation measures significantly enhance learning outcomes (e.g., high utilization rate of online course platforms, project-based teaching reforms covering core professional courses, increasing student participation and achievement in skills competitions)	36	4.06	0.674	4.08	0.280
OP1	Our institution's teaching plan implementation is rigorous and standardized (e.g., courses offered according to talent cultivation programs, practical teaching components fully implemented, clearly publicized teaching progress schedules)	36	3.81	0.920	4.00	0.239
OP2	Our institution completes semester tasks timely and with quality assurance (e.g., examination arrangements without significant errors, teaching materials distributed according to instructional needs, stable partnerships with internship bases formalized through proper agreements)	36	3.67	1.069	4.00	0.239
OP3	Our institution's teaching quality assurance system operates effectively with supporting data (e.g., comprehensive classroom observations by teaching supervisors, student evaluations covering all teaching faculty, complete employment tracking surveys for recent graduates with analytical reports)	36	3.89	0.919	4.00	0.000
OP4	Our institution regularly adjusts professional programs and curricula based on social needs (e.g., phasing out underperforming programs, inviting enterprises to participate in curriculum design, ensuring alignment between training content and job requirements)	36	3.83	1.028	4.03	0.167
OP5	Our institution continuously streamlines and optimizes management service processes (e.g., online academic affairs management system, prompt response mechanism for student complaints, stable electronic records system with online inquiry functionality)	36	3.94	1.013	4.08	0.280
OP6	Our institution's resource utilization efficiency continues to improve (e.g., classroom schedules fully utilized without vacancies, training equipment well-maintained, convenient library borrowing system)	36	3.72	0.944	4.11	0.319
OP7	Our institution effectively applies educational technology to enhance teaching outcomes (e.g., smart classroom coverage in major teaching buildings, widespread utilization of teaching management information platforms, regular information technology training for teaching staff)	36	3.92	0.806	4.72	0.454
ECP1	Our institution's educational resource investments yield measurable benefits (e.g., high weekly utilization rates of training equipment, research results creating tangible value for local enterprises, substantial annual social training projects)	36	3.64	1.018	4.78	0.485
ECP2	Our institution's asset utilization efficiency reaches reasonable levels (e.g., daily classroom scheduling well-filled, dormitory beds mostly occupied, sports facilities open for use during off-hours)	36	3.67	0.986	4.78	0.422
ECP3	Our institution maintains regional competitive advantages (e.g., strong application intent from local candidates, recognized quality of graduate employment, stable provincial-level awards in skills competitions)	36	3.89	0.979	4.78	0.422
ECP4	Our institution's cost control measures are effective (e.g., promoting paperless office procedures, implementing centralized procurement systems, transparent and reasonable administrative expenses)	36	3.75	0.841	4.83	0.378
ECP5	Our institution achieves coordinated development in both scale and quality (e.g., enrollment scale matching faculty resources, implementing vocational skills certificate systems, high satisfaction rates from partner enterprises)	36	3.53	0.941	4.83	0.378
ECP6	Our institution's financial operations are healthy and sustainable (e.g., no major debt risks, standardized student loan management, balanced revenue and expenditure of campus enterprises)	36	3.83	0.878	4.83	0.378
ECP7	Our institution creates significant social and economic value (e.g., graduates' starting salaries higher than regional average, application of technical achievements in enterprises, receiving social donation support)	36	3.78	0.959	4.89	0.319

Variables	QUESTIONNAIRE ITEMS		N	Mean (1st round)	S.D (1st round)	Mean (2nd round)	S.D (2nd round)
Valid N (listwise)	36	Kendall's W[a]	0.037			0.557	

5.1 Research Limitations

The framework faces three key conceptual limitations: it emphasizes structural relationships while inadequately addressing dynamic interactions between components, provides limited consideration of external environmental factors affecting institutional sustainability performance, and requires additional validation of operational performance metrics across diverse institutional contexts to ensure broader applicability and robustness. Future framework validation efforts should pursue three key directions: large-scale empirical testing across diverse institutional settings to enhance generalizability, longitudinal studies to examine framework stability and effectiveness over time, and cross-cultural validation of performance indicators to ensure global applicability. Implementation research priorities should focus on developing detailed practitioner guidelines for framework adoption, investigating context-specific barriers and enablers across different institutional settings, and assessing the framework's impact on institutional performance outcomes through systematic evaluation approaches. Theoretical extension opportunities include examining dynamic capabilities in framework implementation to understand adaptive mechanisms, integrating complementary theoretical perspectives to enrich the conceptual foundation, and developing robust measurement scales for newly identified indicators to enhance empirical validation capabilities.

5.2 Conclusion

This research advances sustainable supply chain performance measurement in higher education through three major theoretical and practical contributions. First, it expands the traditional triple bottom line framework by empirically validating operational performance as a fourth essential dimension. Second, it identifies and validates four distinctive characteristics of higher education supply chains through systematic expert consensus. Third, it develops and validates specific indicators for comprehensive performance measurement across all dimensions. The resulting HESSCP framework, supported by strong expert agreement (Kendall's $W = 0.557$, $p < 0.001$), provides both theoretical advancement and practical guidance for sustainable supply chain management in higher education institutions. The framework's integration of operational performance with traditional sustainability measures offers a more comprehensive approach to performance assessment while acknowledging sector-specific requirements. Future research should focus on empirical validation across diverse institutional contexts, development of implementation guidelines, and theoretical extension through dynamic capabilities perspective. This work lays the foundation for enhanced understanding and implementation of sustainable supply chain practices in higher education, contributing to both academic literature and practical advancement in the field.

Declarations

Data availability: The datasets generated during and/or analysed during the current study are not publicly available due to the need to protect the privacy of experts who participated in the Delphi method but are available from the corresponding author on reasonable request.

Ethical approval: This article does not contain any studies with human participants performed by any of the authors.

Declaration of Conflicting Interests:

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Figures

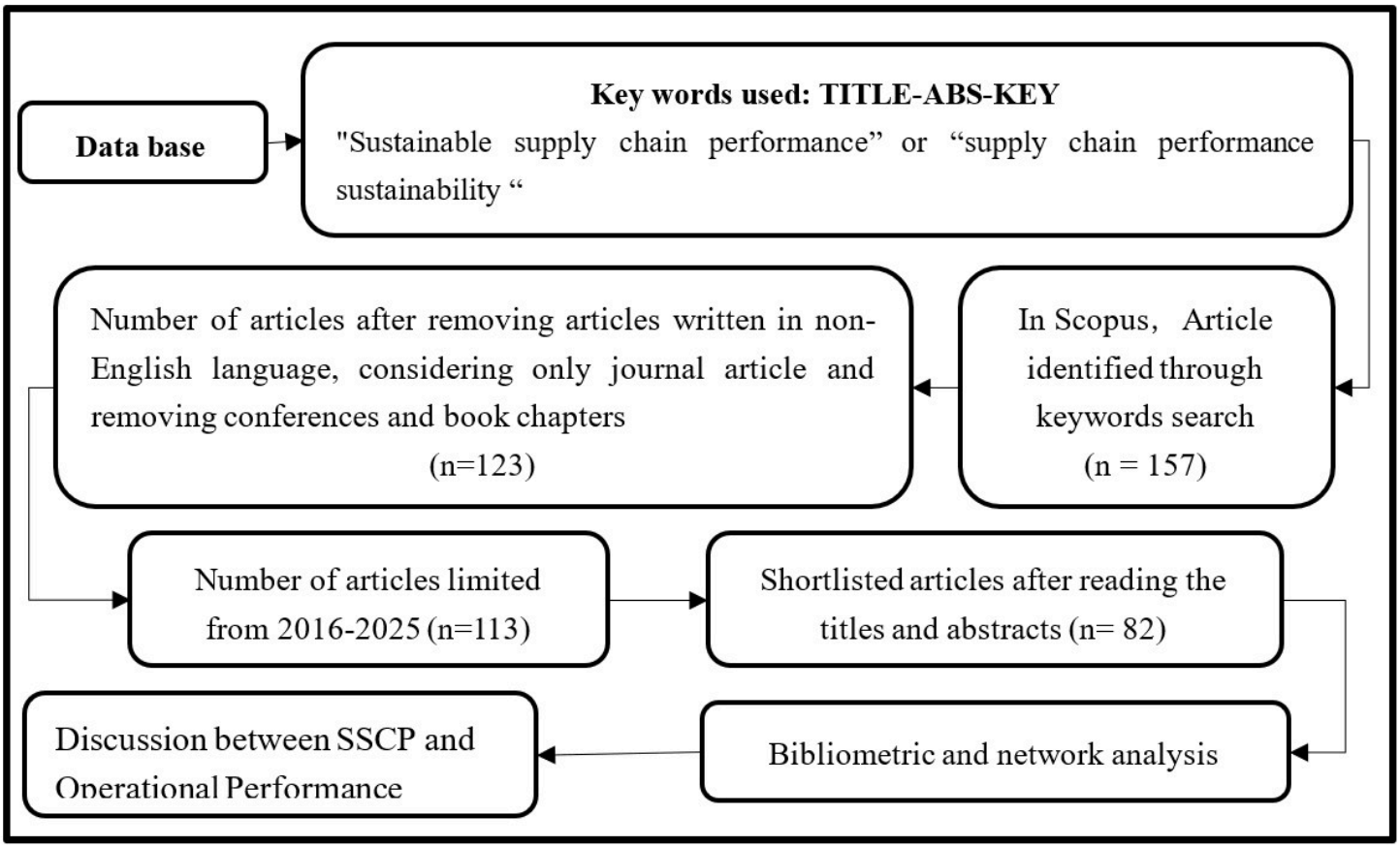


Figure 1

Methodology (Source: Author using Scopus database)

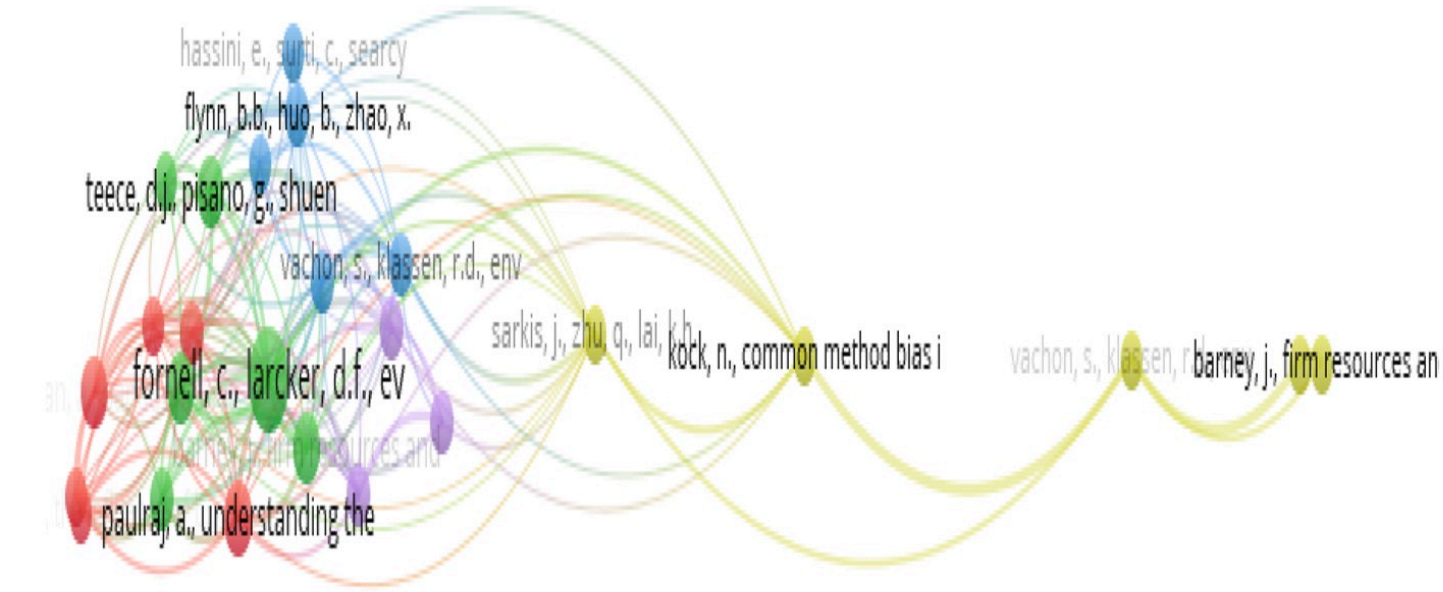


Figure 2

Network visualization of Co-citation Analysis (Source: Author using VOSviewer)

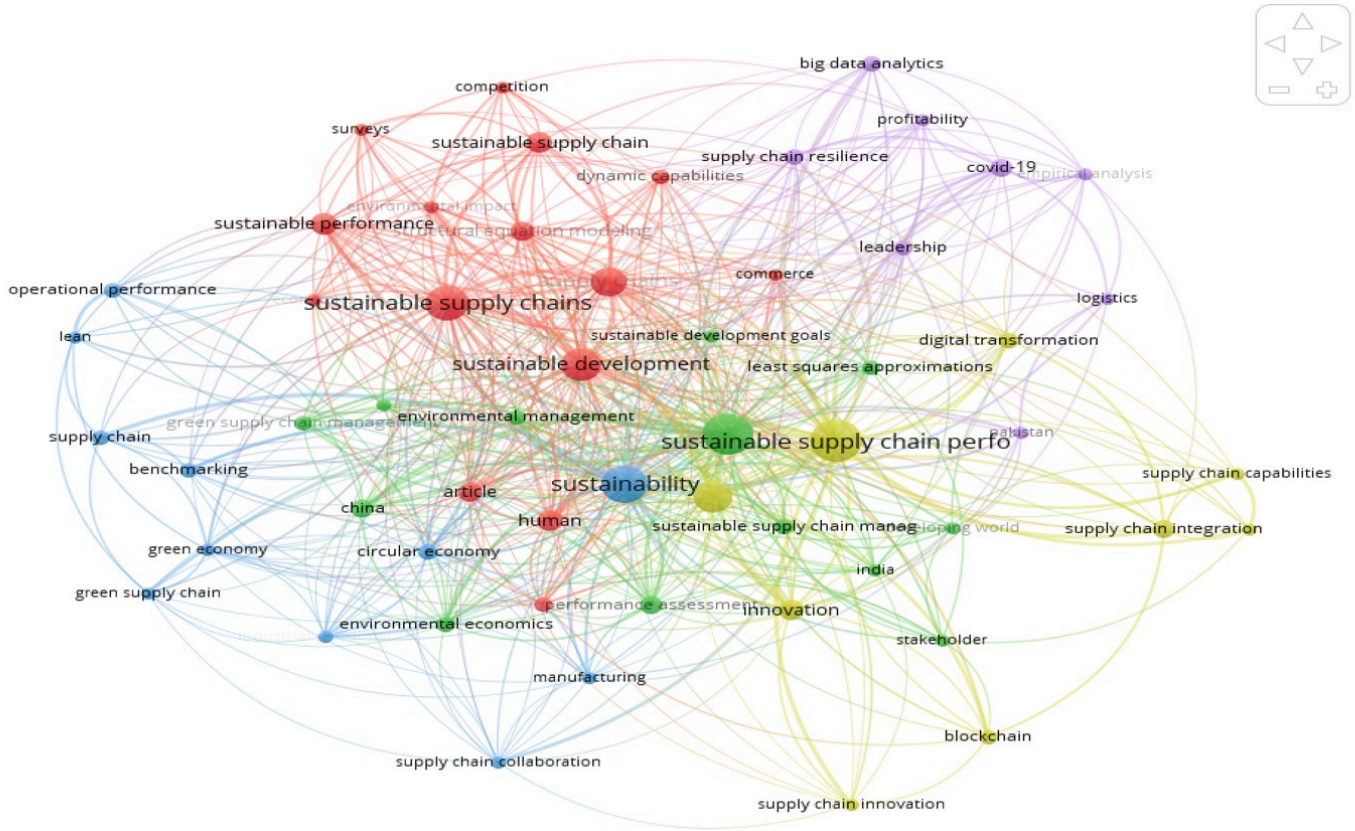


Figure 3

Network Visualization of Co-occurrence Analysis of Keywords Analysis (Source: Author using VOSviewer)

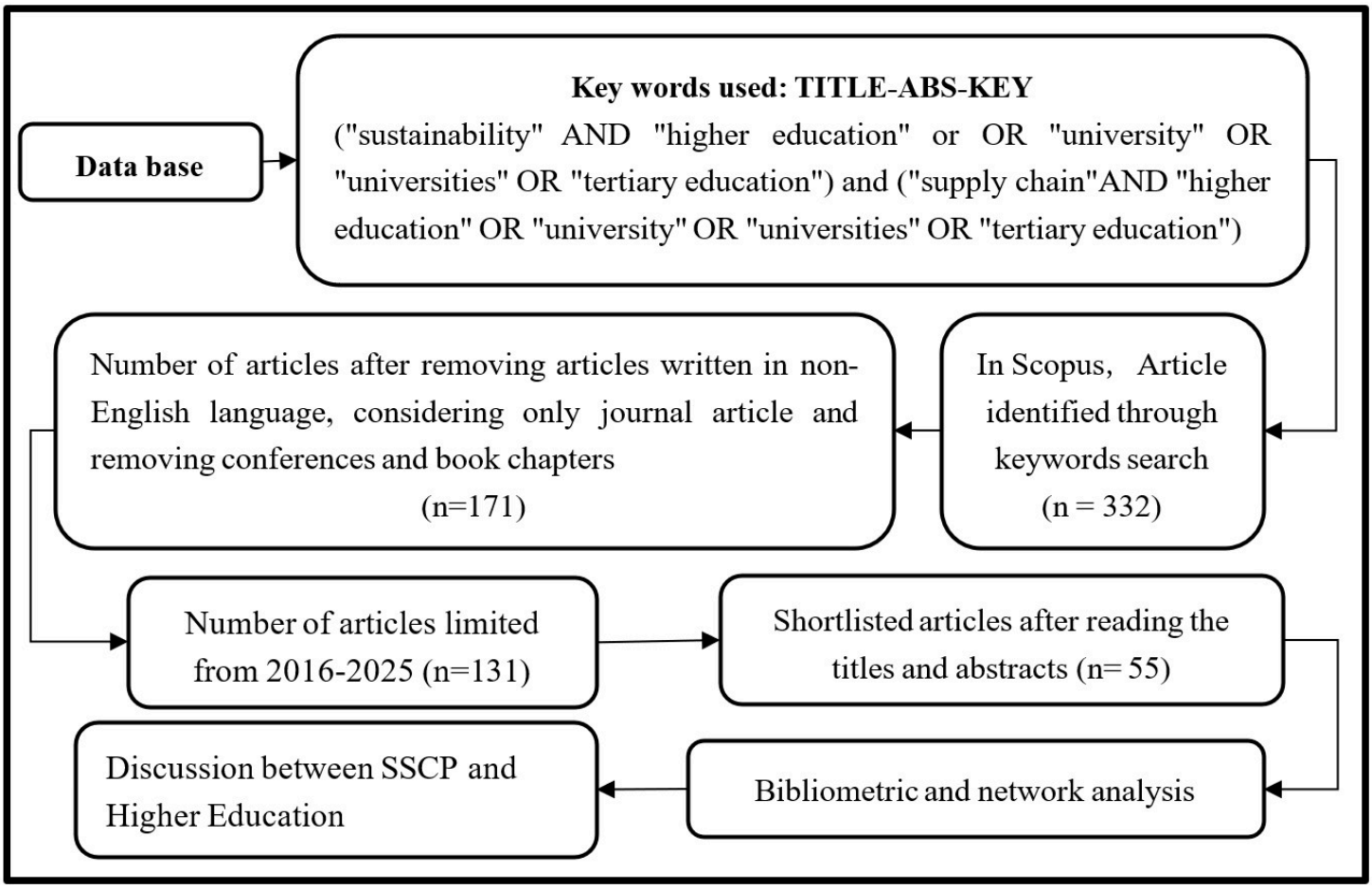


Figure 4

Methodology (Source: Author using Scopus Database)

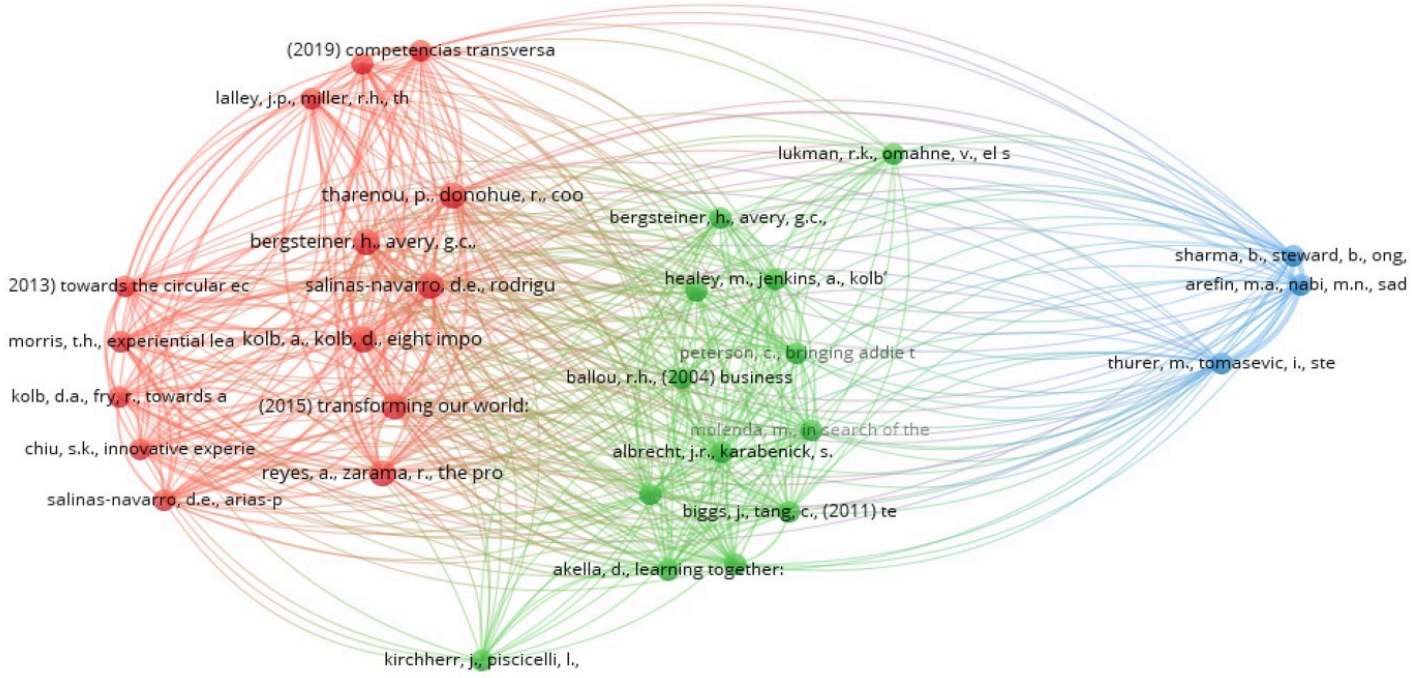


Figure 5

Network visualization of Co-citation Analysis (Source: Author using VOSviewer)

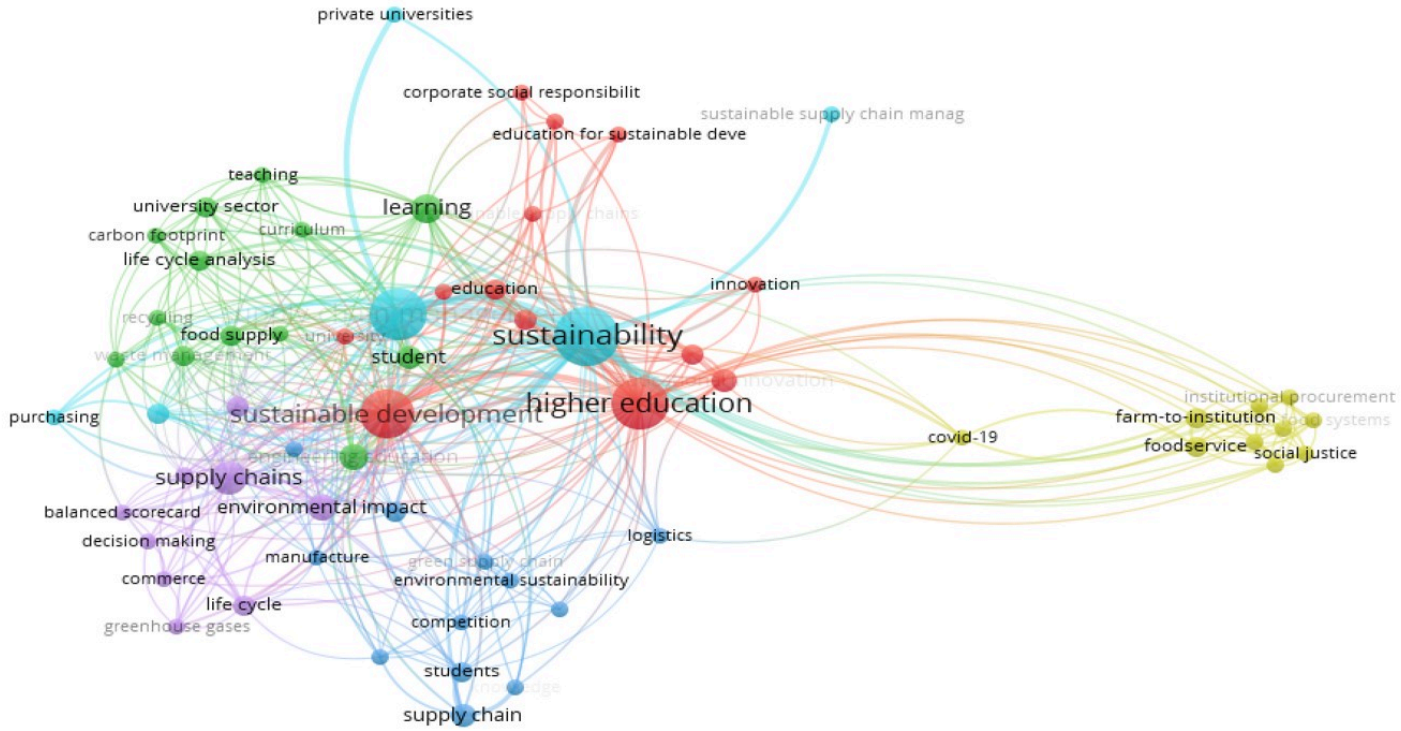


Figure 6

Network Visualization of Co-occurrence of Keywords Analysis (Source: Author using VOSviewer)

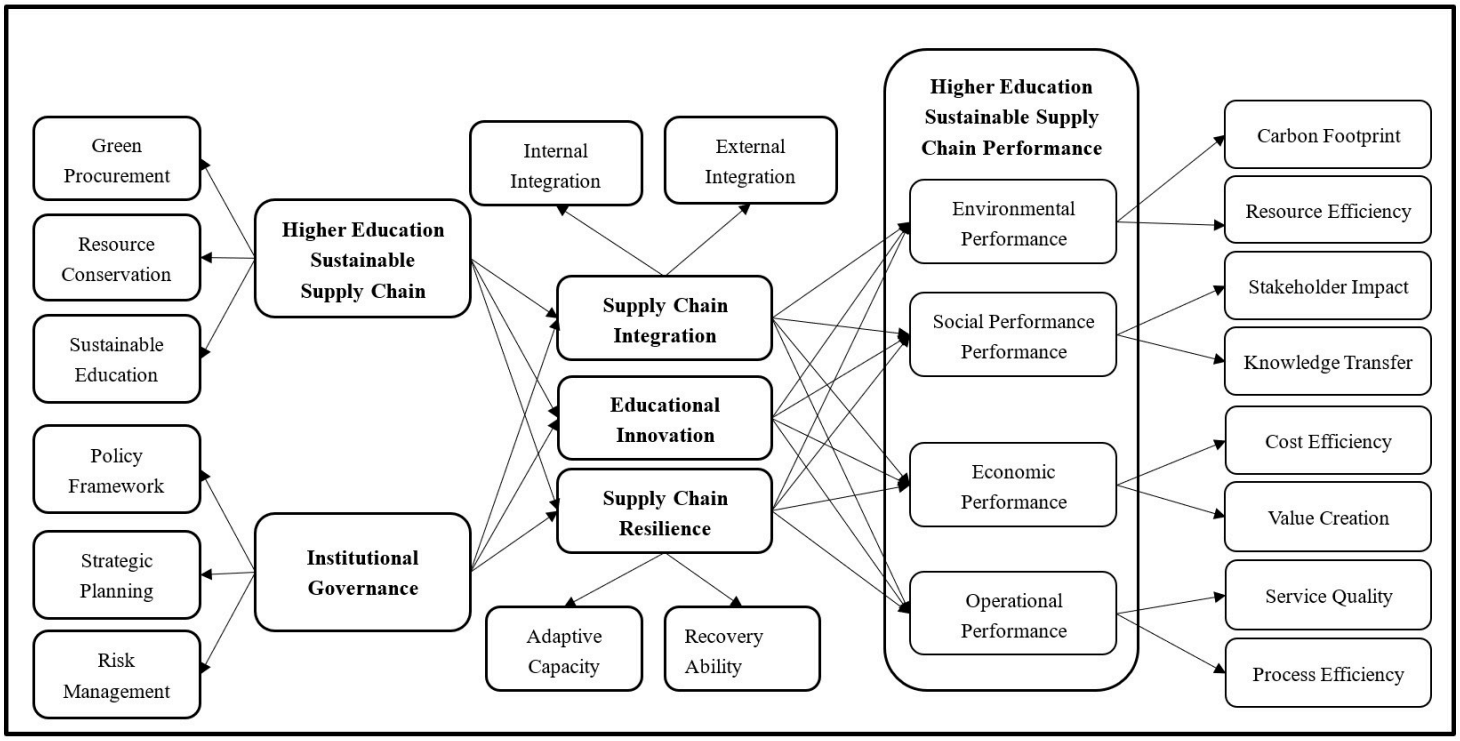


Figure 7

Integrated Conceptual Framework based SSCP, Operational Performance and Higher Education (Source: Author)

Supplementary Files

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- Appendix.docx