

Clustering Companies by Sustainability Behavior: A Comparative Study between Industrial and Non-Industrial Sectors

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Abstract

This study aims to classify the sustainability behavior of companies listed on the Stock Exchange of Thailand using cluster analysis to reflect the level of ESG maturity and compare it between industries and non-industries. The sample consisted of 503 companies in 2023. Variables used for clustering included Sustainability Disclosure Score (GRI Score), Corporate Governance Scores (CG Score), Return on Equity (ROE), and Financial Risk (D/A Ratio). Industry type was excluded from the clustering model and analyzed later.

Analysis using Partitioning Around Medoids and Gower distance revealed that companies could be classified into three groups: low ESG levels, medium ESG levels, and high ESG levels. Statistical tests confirmed significant differences in GRI scores and corporate governance quality between groups, while ROE and financial risk levels did not. Furthermore, a weak linear relationship was observed between groups and industry type. Theoretically, the research supports institutional and stakeholder theories, indicating that differences in sustainability stem more from governance quality and disclosure ability than from financial factors. This research offers policy recommendations for designing appropriate ESG promotion measures based on the readiness of organizations in the Thai capital market.

Keywords: Sustainability, ESG, Cluster Analysis

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Introduction

Over the past decade, the concept of sustainability has become a key issue in shaping the direction of global business operations, with environmental, social, and governance (ESG) considerations receiving increasing attention from investors, regulators, and consumers (Eccles & Klimenko, 2019, pp. 106-116). These forces have encouraged companies to operate with greater transparency, assume responsibility for their impacts, and strengthen their corporate governance systems. One of the widely accepted mechanisms used to demonstrate a company's commitment to sustainability is the disclosure of sustainability information in accordance with the Global Reporting Initiative (GRI), which enables stakeholders to consistently evaluate sustainability performance across firms (KPMG, 2022, pp. 15-18). In addition, corporate governance scores serve as another important indicator reflecting the quality of governance systems and influencing credibility and investment decisions (Mallin, 2019, p. 30).

Although sustainability has become a global priority, ESG responses vary considerably across industries due to differences in regulatory environments, stakeholder pressure, operational risk exposure, and institutional expectations. Prior research suggests that industry-level characteristics shape firms' motivations and capacities to engage in sustainability disclosure and ESG management (Fernando & Lawrence, 2014, pp. 200-223; Li, Li, & Minor, 2021, pp. 125-145). From the viewpoint of institutional theory, industrial sectors that face stronger coercive, normative, or mimetic pressures are more likely to adopt extensive ESG practices, while non-industrial sectors may experience distinct stakeholder expectations and adopt different sustainability strategies. These sector-specific institutional conditions provide a theoretical justification for comparing ESG behaviors across industrial and non-industrial firms.

Cluster analysis has been widely used to classify companies based on patterns of sustainability performance, offering insight into heterogeneous ESG behaviors and enabling systematic grouping based on shared characteristics (Hair, Black, Babin, & Anderson, 2010, p. 477). However, empirical studies within the Thai context remain limited, particularly those that investigate how firms in different sectors diverge in sustainability disclosure, corporate governance quality, and financial risk. Existing Thai studies rarely incorporate sector-based institutional differences or examine how these differences influence sustainability behavior. This gap is increasingly important as recent evidence indicates that Thai industrial and non-industrial sectors operate under distinct competitive conditions, regulatory pressures, and stakeholder demands (Stock Exchange of Thailand, 2023, p. 145; Charoenrat & Amornkitvikai, 2021, pp. 1-20).



Based on these limitations, the research problem addressed in this study concerns the absence of empirical evidence on whether and how listed companies in different sectors of the Thai capital market exhibit distinct patterns of sustainability behavior. Understanding these differences is crucial for identifying sector-specific ESG strategies and for supporting policymakers, regulators, and firms in designing more effective sustainability promotion guidelines. Therefore, this study employs statistical clustering techniques to identify patterns of sustainability behavior among Thai listed companies and to generate comparative insights between industrial and non-industrial sectors, with the objective of enhancing understanding of ESG dynamics within the Thai business environment.

Research Objectives

1. To classify companies in the Stock Exchange of Thailand according to their sustainability behavior using GRI variables, CG Score, Profitability, and Financial Risk.
2. To describe the characteristics of each cluster obtained from the analysis.
3. To compare the proportion of companies in each cluster between industrial and non-industrial sectors.

Scope of Research

The sample group in this research consisted of 503 listed companies in the Stock Exchange of Thailand (SET) in 2023. Only companies with complete data on the variables used in the study were selected, including sustainability scores according to the GRI framework (GRI Score), Corporate Governance Score (CG Score), Profitability (ROE), Financial Risk (D/A Ratio), and industry classification data (industry/non-industry). Companies in the financial industry group, including banks, insurance companies, and securities companies, as well as real estate investment trusts (REITs), were excluded from the study because these companies have different business structures, financial statements, and reporting formats from the general business sector, which may affect the analysis and classification of clusters (Chancharat, Krishnamra, & Suriyamanee, 2022, pp. 45-62; The Stock Exchange of Thailand, 2023, pp. 15-18). The sample group selection used a purposive sampling method, considering companies that had disclosed information to the public completely and continuously throughout the data collection period to ensure that the analysis results are accurate and reliable.

Conceptual Framework

The content will be part of the research conceptual framework and the explanation of the variables in the research conceptual framework.

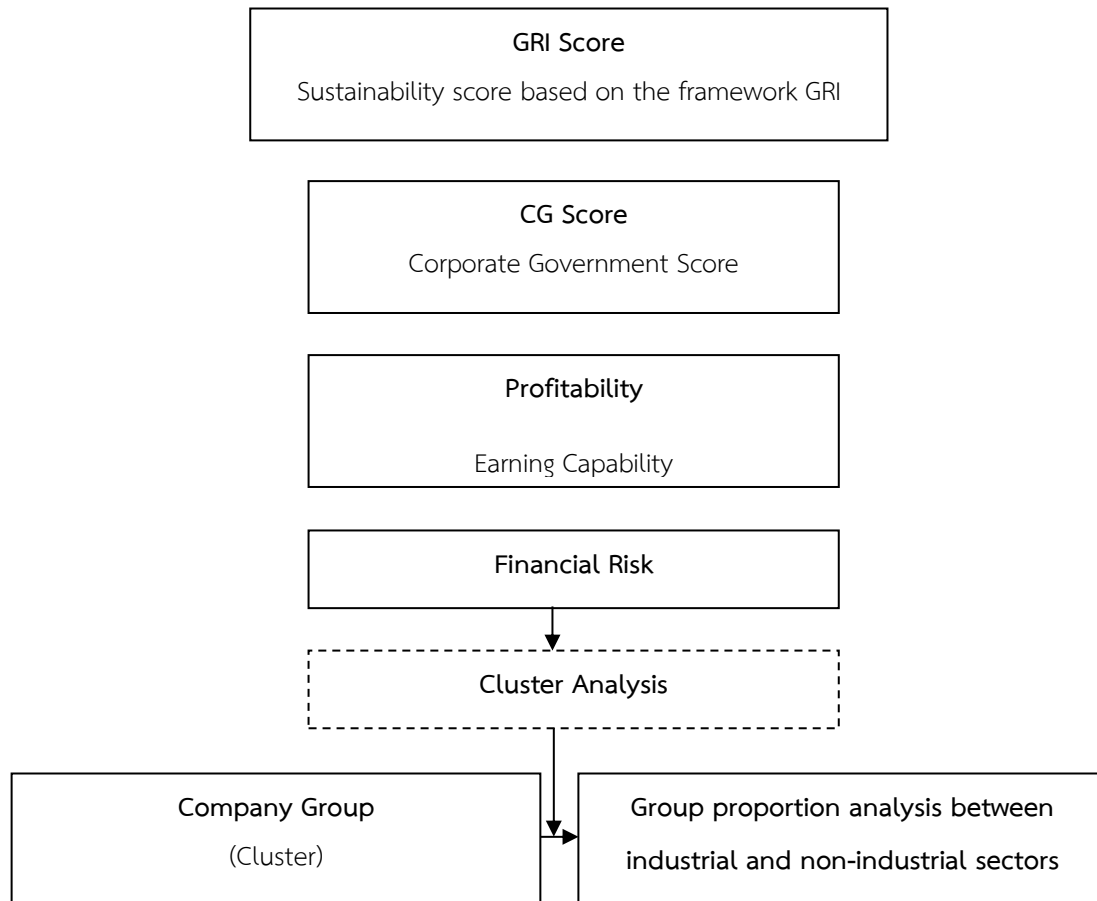


Figure 1 Conceptual Framework

Table 1 Variable Descriptions in the Research Framework

Variable Type	Variable	Description
Clustering Input Variables	1. GRI Score	Sustainability score based on the GRI framework
	2. CG Score	Corporate governance score
	3. Profitability	Earning capability
Clustering Input Variables	4. Financial Risk	Financial risk
Comparison Variable	5. Industry Type	Company type: Industrial / Non-industrial

Literature Review

Sustainability Disclosure and ESG

The concept of sustainability has become central in shaping business strategies, especially with the increasing relevance of Environmental, Social, and Governance (ESG) dimensions. Organizations are now expected to disclose their sustainability efforts transparently in alignment with global standards such as the Global Reporting Initiative (GRI), which enables stakeholders to assess their ESG performance comprehensively (KPMG, 2022, pp. 15-18). Eccles & Klimenko (2019, pp. 106-116) emphasized that the pressure from investors and regulatory bodies has shifted sustainability from a voluntary practice to a strategic imperative.

According to Freeman's (1984, p. 111) stakeholder theory, sustainability disclosure serves as a communication mechanism that reduces information asymmetry and enhances an organization's accountability to multiple stakeholders. Therefore, GRI scores have become an important indicator of how effectively an organization meets stakeholder expectations. Recent empirical research (Baumgartner et al., 2022, pp. 361-389; Winit et al., 2023, pp. 1-18) shows that higher levels of GRI disclosure enhance stakeholder trust and bring about corporate reputational benefits.

Corporate Governance and ESG Transparency

Corporate governance is another vital dimension that correlates with ESG transparency and investor confidence. Good governance systems not only mitigate agency problems but also increase firm accountability and reputation (Mallin, 2019, p. 30). Companies with robust governance structures are more likely to produce credible ESG reports and adopt sustainable business models.

According to DiMaggio and Powell's (1983, pp. 147-160) institutional theory, the quality of corporate governance reflects institutional pressures such as regulatory requirements, professional norms, and market expectations. A high CG score indicates that an organization adheres to institutionally accepted standards of governance and ethical behavior. Recent research (Amorelli & García-Sánchez, 2021, pp. 1-18; Husted & de Sousa-Filho, 2022, pp. 923-952) also found that effective governance mechanisms enhance ESG transparency and reduce the likelihood of symbolic or superficial disclosures.

Industry Type and ESG Behavior

Studies have found that ESG practices often vary by industry due to differing operational, regulatory, and stakeholder contexts. Fernando & Lawrence (2014, pp. 200-223) noted that firms in environmentally sensitive industries face greater scrutiny, prompting them

to disclose more sustainability information. In contrast, service-oriented sectors may adopt ESG practices more proactively due to their flexibility and stakeholder engagement models.

According to Suchman's (1995, pp. 571-610) legitimacy theory, firms operating in high-impact industries such as manufacturing typically face stronger societal expectations and, as a result, tend to disclose ESG information more proactively to maintain their legitimacy. Recent empirical evidence (Kim & Lyon, 2023, pp. 345-362; Zhuang, Chang, & Lee, 2021, pp. 985-1007) indicates that firms in industrial sectors tend to report ESG information more prominently in response to public concerns and mitigate threats to corporate legitimacy

Cluster Analysis in ESG Research

Cluster analysis offers a powerful method for segmenting companies based on ESG-related behaviors, allowing researchers to explore hidden patterns without pre-defined categories (Hair, Black, Babin, & Anderson, 2010, p. 477). Eccles, Loannou, & Serafeim (2014, pp. 2835-2857) further categorized companies along an ESG maturity spectrum from reactive to proactive ESG strategists highlighting the diversity of sustainability adoption across firms. The application of cluster analysis thus provides valuable insights into strategic groupings and enables benchmarking within and across industries.

Recent research (Della Torre, Mango, & Rizzo, 2022, pp. 344-369; Liu & Wu, 2023, p. 7895) supports the use of clustering techniques to classify companies based on their sustainability behavior, governance quality, and financial characteristics. Applying clustering analysis to GRI scores, CG scores, profitability, and financial risk can reveal strategic groupings of companies and facilitate effective cross-industry comparisons.

Research Gap and Contextual Relevance

In the Thai context, prior ESG research has predominantly focused on linear relationships between sustainability performance and firm outcomes (Chancharat, Krishnamra, & Suriyamanee, 2022, pp. 45-62). Limited studies have explored how Thai firms can be classified based on ESG behaviors, particularly in terms of industry comparisons. This study aims to fill that gap by examining the influence of financial performance, risk, governance, and industry context on ESG behavior using cluster analysis.

Considered from the perspectives of stakeholder theory, institutional theory, and legitimacy theory, ESG behavior is multidimensional and influenced by information disclosure, governance quality, profitability, leverage, and industry context. The research gap in using clustering to study ESG has limited understanding of the classification of Thai companies

according to these characteristics and the role of industry type in clustering patterns. This study aims to bridge this gap by applying clustering analysis to GRI disclosures, CG Scores, Return on Equity (ROE), and Debt-to-Asset (D/A Ratio) in different industry contexts.

Hypotheses Development

Based on the above review, the following hypotheses are proposed:

H1: Listed companies in Thailand are expected to form distinct clusters based on their ESG-related attributes (GRI Score, CG Score, ROE, and D/A Ratio).

H2: The clusters are expected to show differences in ESG performance (GRI Score and CG Score).

H3: Industry type (industrial vs. non-industrial) is expected to be associated with cluster membership, rather than determining it.

H4: Differences in profitability (ROE) and financial risk (D/A Ratio) are not expected to be significant among the ESG clusters.

Methodology

This study employs a quantitative research design to classify companies based on their sustainability behavior using appropriate multivariate clustering techniques for mixed-type data. The methodology consists of four major stages: Data Preparation, Variable Measurement, Clustering Procedure, and Post-clustering Validation.

Stage1: Data Preparation and Preprocessing

Before conducting the clustering analysis, the dataset underwent a systematic data cleaning and preprocessing process to ensure accuracy and analytical robustness.

1. Handling Missing Data:

Missing values were examined using descriptive diagnostics and were handled by applying median imputation for continuous variables and mode imputation for binary variables to minimize distortion in data distribution.

2. Treatment of Outliers:

Outliers in continuous variables (e.g., financial ratios) were detected using the interquartile range (IQR) method and winsorized at the 1st and 99th percentiles to reduce extreme-value influence.

3. Standardization of Variables:

All continuous variables (Sustainability Score, ROE, Financial Risk ratio) were standardized using z-scores prior to clustering to ensure equal weighting regardless of scale. This step is essential because clustering algorithms are sensitive to variable scale.

4. Data Type Specification:

Industry Type was treated strictly as a post-clustering categorical variable (not as a clustering input) to avoid bias, consistent with mixed-data clustering standards.

Stage 2: Measurement of Variables

Table 2 summarizes the variable definitions, measurement methods, and data sources following reviewer recommendations.

Table 2 Measurement of Variables

Variable Name	Measurement Method	Source
Sustainability	Disclosure score based on the Global Reporting Initiative (GRI) Standards (GRI 2021) covering economic, environmental, and social categories	Company Sustainability Reports, SET Market Data
Industry Type	Dummy variable: 1 = Industrial sector, 0 = non-industrial sector (used only for Post-hoc analysis)	SET Industry Classification
Financial Risk	Debt-to-Assets Ratio (D/A) = $\frac{\text{Total Debt}}{\text{Total Assets}}$	SETSMART / Company Financial Statements
Profitability	ROE = $\frac{\text{Net Profit}}{\text{Total Equity}}$	SETSMART
Corporate Governance	Corporate Governance Score from IOD's Corporate Governance Report (CGR): 1 = Excellent/Very Good, 0 = Others	Thai IOD CGR Database

Stage 3: Clustering Technique

Given that the dataset contains both continuous variables (e.g., ROE, D/A Ratio, Sustainability Score) and binary variables (CG Score), a clustering method suitable for mixed-type data was applied.

Distance Metric

Gower Distance

Gower's coefficient was used to compute pairwise dissimilarities, as it supports mixed data types and prevents bias from high-scale variables.



Clustering Algorithm

Partitioning Around Medoids (PAM / k-medoids)

The PAM algorithm was applied because it is robust to noise, appropriate for mixed data, and compatible with Gower Distance, unlike K-means which requires continuous variables and Euclidean Distance.

Determining the Optimal Number of Clusters

To justify and validate the selection of the number of clusters:

1. Elbow Method (using within-cluster dissimilarity)
2. Average Silhouette Width
3. Gap Statistic

These three criteria were computed, and the number of clusters was selected based on convergence of evidence from all metrics rather than arbitrary assignment.

Stage 4: Post-Clustering Statistical Validation

After obtaining cluster groups, statistical procedures were applied to test the distinctness and interpretability of the clusters.

Differences in Continuous Variables

1. ANOVA was used when the variable met normality and homogeneity assumptions.
2. Kruskal-Wallis Test was applied for non-normal distributions.

This confirmed whether Sustainability Score, ROE, and Financial Risk differed significantly between clusters.

Differences in Corporate Governance Score (binary variable)

3. Chi-square Test of Independence

Used to examine whether CG score patterns varied significantly across clusters.

Industry Composition Analysis

Industry Type was analyzed only after clustering using the Chi-square Test to identify whether industrial vs. non-industrial companies were unevenly distributed across clusters.

This approach ensures that industry classification interprets cluster behavior rather than influences cluster formation.



Results

Descriptive Statistics

Table 3 Descriptive Statistics of the Variables

Variable	N	Minimum	Maximum	Mean	Standard Deviation
GRI Score	503	23	74	42.1	8.65
CG Score	503	0	1	0.71	0.45
Profitability (ROE)	503	-4.8	3.95	0.07	0.34
Financial Risk (D/A)	503	0.02	1.75	0.46	0.22
Industry Type (Post-hoc only)	503	0	1	0.52	0.5

From Table 3, the descriptive statistics of 503 listed companies show that the sustainability disclosure score (GRI Score) has a mean value of 42.10 with moderate variability (standard deviation of 8.65), indicating noticeable differences in sustainability reporting levels among firms. The Corporate Governance Score (CG Score) also shows variation, with a mean of 0.71 and a standard deviation of 0.45, suggesting that a majority of companies demonstrate acceptable to relatively strong governance practices, while some firms still lag behind.

Profitability, measured by Return on Equity (ROE), shows a relatively low average level of 0.07 but a wide dispersion (standard deviation of 0.34), reflecting substantial heterogeneity in firm performance. Financial Risk, measured by the Debt to Assets Ratio (D/A Ratio), exhibits moderate variation, with a mean of 0.46 and a standard deviation of 0.22, indicating differences in leverage levels across companies. Industry Type shows a relatively balanced distribution between industrial and non industrial firms, supporting its suitability for post-hoc comparison rather than use as a clustering input.

Cluster Analysis Results

To determine the appropriate number of clusters, multiple diagnostic criteria were applied, including the Elbow Method, Average Silhouette Width, and Gap Statistic. The results from all three measures consistently support a three cluster solution. Specifically, the average silhouette width reaches its highest value at k equals 3, while both the Gap Statistic and the Elbow criterion indicate diminishing marginal improvements when additional clusters are introduced. This convergence of evidence suggests that a three-cluster solution provides the



most appropriate balance between cluster separation and within cluster homogeneity. Detailed diagnostic results are reported in Appendix A.

Based on this determination, the clustering analysis was conducted using the Partitioning Around Medoids algorithm with Gower Distance, incorporating four input variables: GRI Score, CG Score, Profitability measured by ROE, and Financial Risk measured by the Debt to Assets Ratio. Industry type was deliberately excluded from the clustering inputs and examined only in post-hoc analysis to avoid methodological bias. The final solution classifies firms into three clusters, and the resulting cluster profiles are presented in Table 4.

Table 4 Cluster Analysis Results

Variable	Cluster 1:	Cluster 2:	Cluster 3:
	Low ESG	Moderate ESG	High ESG
	Maturity	Maturity	Maturity
	(n=176)	(n=244)	(n=83)
GRI Score (Mean)	34.1	45.8	59.6
CG Score (Proportion = 1)	0.58	0.72	0.91
Profitability (ROE)	0.05	0.08	0.07
Financial Risk (D/A)	0.49	0.44	0.41

From Table 4, the companies can be clearly grouped into three distinct clusters based on their sustainability and governance characteristics. Cluster 3 shows the highest performance in both dimensions, with the highest average GRI Score of 59.60 and the highest proportion of firms with high Corporate Governance Scores (CG = 0.91), indicating that companies in this group demonstrate the strongest sustainability disclosure practices and the most robust governance structures. In contrast, Cluster 1 exhibits the lowest mean scores, with a GRI Score of 34.10 and a CG Score of 0.58, reflecting substantially weaker ESG maturity relative to the other clusters. Cluster 2 lies between the two, with moderate levels of sustainability disclosure and governance quality (GRI = 45.80; CG = 0.72), and represents the largest proportion of firms in the sample (244 companies), followed by Cluster 1 (176 companies) and Cluster 3 (83 companies).

With respect to financial characteristics, the mean Profitability (ROE) and Financial Risk (D/A Ratio) do not display pronounced differences across clusters. Profitability remains relatively comparable among the three groups, while Financial Risk shows a modest declining pattern from the low-ESG cluster to the high-ESG cluster. This pattern suggests that financial performance and leverage are not the primary factors driving cluster differentiation. Despite not being the largest group, Cluster 3 clearly stands out as the ESG leader, reinforcing the notion that higher sustainability and governance quality are not necessarily associated with cluster size or superior short-term financial outcomes.

Cluster Characteristics

To further illustrate the characteristics of the clusters identified in the revised PAM Gower solution, this section examines patterns of sustainability disclosure, corporate governance quality, and financial attributes across the three groups. As summarized in Table 4, the clusters primarily differ in terms of ESG related dimensions, particularly sustainability disclosure and governance quality, rather than financial performance. Firms in Cluster 3 exhibit the highest level of ESG maturity, characterized by substantially higher GRI disclosure scores and a greater proportion of companies with strong corporate governance practices. In contrast, Cluster 1 represents firms with comparatively weaker sustainability disclosure and governance structures, suggesting lower organizational readiness for ESG integration. Cluster 2 occupies an intermediate position, reflecting firms that have achieved moderate levels of ESG development and may be in a transitional stage toward more advanced sustainability practices.

With respect to financial characteristics, the mean levels of profitability and financial risk appear broadly comparable across clusters, with no pronounced separation observed at the descriptive level. This pattern indicates that although firms differ meaningfully in their ESG related attributes, such differences are not necessarily accompanied by systematic variation in short term financial performance or leverage. To formally assess whether the observed differences are statistically significant, post clustering inferential tests are conducted and reported in Table 5.

Table 5 Statistical Tests of Differences Across Clusters (Post-clustering Validation)

Variable	Test	Test Statistic	df	p-value
GRI Score	One-way ANOVA	F = 865.42	(2, 500)	< 0.001
CG Score	Chi-square test	$\chi^2 = 14.87$	2	< 0.001
Profitability (ROE)	One-way ANOVA	F = 0.94	(2, 500)	0.39
Financial Risk (D/A)	One-way ANOVA	F = 1.21	(2, 500)	0.298

From Table 5, the results of the post clustering statistical tests used to compare key variables across the three clusters show clear differences in sustainability related factors, while financial variables do not differ significantly. The one-way ANOVA results indicate that the GRI Score differs significantly among the clusters, with a high F value and a p value lower than 0.001. This finding confirms that sustainability disclosure levels play a major role in distinguishing the clusters. In addition, the Chi-square Test for the Corporate Governance Score also shows a statistically significant difference across clusters, suggesting that governance quality varies meaningfully among firms with different levels of ESG maturity.

In contrast, the results for financial characteristics do not show statistically significant differences. Profitability measured by ROE yields an F value of 0.94 with a p value of 0.390, while Financial Risk measured by the Debt to Assets Ratio shows an F value of 1.21 with a p value of 0.298. These results indicate that short term financial performance and leverage levels are relatively similar across the three clusters.

Overall, these findings suggest that although companies differ clearly in terms of sustainability disclosure and governance quality, financial performance and financial risk do not statistically distinguish the clusters. This supports the interpretation that the clustering structure is primarily driven by ESG related characteristics, especially sustainability disclosure and governance practices, rather than by financial outcomes when considered individually.

Table 6 Association Between Cluster Membership and Industry Type Post-hoc Analysis

Statistic	Value	df	p value
Pearson Chi-square	7.84	2	0.097
Likelihood Ratio	7.99	2	0.092
Linear by Linear Association	4.21	1	0.04

From the analysis of the relationship between the cluster groups and industry type using the Chi-square Test, the Pearson Chi-square value is 7.84 with a p value of 0.097, which is slightly higher than the conventional significance level of 0.05. Therefore, based on this statistic, it cannot be concluded that there is a statistically significant overall association between cluster membership and industry type.

However, the Likelihood Ratio statistics show a value of 7.99 with a p value of 0.092. Although this p value is lower than that of the Pearson Chi-square Test, it still does not reach the 0.05 threshold. This result similarly suggests that the relationship between cluster membership and industry type is not statistically significant under this criterion.

Nevertheless, the Linear-by-Linear Association statistics, which examine the presence of a trend relationship between the two variables, has a value of 4.21 with a p value of 0.040. This finding indicates a weak but statistically significant linear trend between cluster membership and industry type. In other words, although the overall association is not strong enough to be detected by the Pearson Chi Square or Likelihood Ratio tests, there is evidence of a modest directional pattern linking sustainability related cluster grouping with the type of industry in which companies operate.

Discussion

The overall research results reflect several important aspects regarding the sustainability behavior of listed companies in Thailand. The descriptive results show that firms differ clearly in terms of sustainability disclosure and corporate governance quality, as reflected in the revised cluster profiles. Companies in the sample exhibit varying levels of ESG maturity, with sustainability disclosure scores and governance practices differing substantially across groups. In contrast, financial indicators such as profitability and financial risk display relatively similar patterns across clusters, indicating that firms with different levels of ESG maturity do not necessarily differ in their short-term financial performance or leverage structure.

The cluster analysis helps to clarify these differences by identifying three distinct groups of companies. Cluster 3 represents firms with the highest level of ESG maturity, characterized by the strongest sustainability disclosure practices and the highest proportion of firms with strong corporate governance. These firms reflect a more strategic and integrated approach to ESG implementation. Cluster 1 consists of companies with lower sustainability disclosure levels and weaker governance structures, suggesting limited organizational readiness for ESG adoption or a more compliance-oriented approach. Cluster 2 lies between

these two groups and represents firms with moderate ESG development, indicating that a large proportion of listed companies are in a transitional stage of sustainability adoption as they gradually respond to increasing stakeholder and regulatory expectations.

The post clustering statistical tests reported in Table 5 further support these observations. The results confirm that sustainability disclosure and corporate governance quality differ significantly across clusters, while profitability and financial risk do not show statistically significant differences. This implies that financial performance and leverage are not the primary factors determining ESG cluster membership. Instead, the clustering structure is driven mainly by ESG related characteristics, particularly sustainability disclosure and governance practices. This finding is consistent with the ESG literature, which emphasizes that sustainability leadership is shaped more by corporate strategy, governance quality, and disclosure capability than by financial outcomes alone.

The comparison of clusters by industry type adds another dimension to the interpretation. The results in Table 6 show that the Pearson Chi-square and Likelihood Ratio tests do not indicate a statistically significant overall association between cluster membership and industry type. However, the Linear-by-Linear Association reveals a weak but statistically significant trend, suggesting a modest directional relationship between industry type and ESG cluster membership. This finding indicates that while industry classification does not determine ESG maturity, companies in certain industries may be more likely to exhibit higher or lower levels of ESG development. From an institutional theory perspective, this pattern may reflect differences in regulatory pressure, societal expectations, and industry norms that influence firms' sustainability behavior. Stakeholder theory similarly suggests that firms operating in industries with more influential stakeholders may face stronger incentives to improve sustainability disclosure and governance practices.

Nevertheless, the absence of a strong overall association between industry type and cluster membership suggests that internal organizational factors play a more important role than industry structure in shaping sustainability behavior. Factors such as governance strength, organizational culture, and sustainability strategy appear to be more critical drivers of ESG maturity than financial conditions or industry classification alone. Overall, the revised findings reinforce the view that differences in corporate sustainability behavior among Thai listed companies are primarily driven by internal systems and strategic choices, highlighting the importance of governance driven and systematically managed ESG practices within organizations.

Conclusion

From the analysis of data from 503 listed companies in the Stock Exchange of Thailand using a revised cluster analysis approach based on sustainability and financial variables, including GRI Score, CG Score, Profitability, and Financial Risk, the findings indicate that companies can be classified into three distinct clusters with clearly different levels of sustainability performance and governance quality. The first cluster represents firms with relatively low levels of sustainability disclosure and weaker corporate governance practices, suggesting limited ESG readiness or a lower organizational emphasis on transparency. Although their profitability and financial risk levels are broadly comparable to those of other clusters, the descriptive patterns indicate that these firms may face greater challenges in responding to evolving ESG expectations.

The second cluster reflects companies with moderate levels of sustainability disclosure and governance quality. As the largest group in the sample, this cluster appears to represent firms that are in a transitional stage of ESG maturity, gradually developing sustainability practices in response to increasing regulatory requirements and stakeholder pressures. The characteristics of this group suggest an adaptive approach to ESG engagement rather than a fully proactive or strategically integrated model.

The third cluster consists of companies with the highest sustainability disclosure scores and the strongest governance structures. Despite not being the largest group, firms in this cluster exhibit patterns consistent with more advanced ESG integration. Their strong performance in sustainability and governance is more likely to reflect higher strategic commitment and organizational capacity rather than differences in short term financial performance or industry structure. The Post-hoc analysis further reveals only a weak linear trend between cluster membership and industry type, indicating that while industry context may influence ESG orientation to some extent, it does not fully determine a firm's level of ESG maturity.

From a theoretical perspective, the findings contribute to the understanding that sustainability differentiation among firms is driven primarily by organizational governance quality and disclosure capability rather than by financial characteristics. This supports institutional and stakeholder perspectives, which emphasize that firms progress in ESG maturity due to normative pressures, strategic choices, and internal governance mechanisms rather than financial conditions alone.

From a managerial perspective, the results provide practical implications for both firms and policymakers. Companies in the low ESG cluster may benefit from targeted capacity building initiatives, governance strengthening efforts, and improvements in sustainability reporting systems. Firms in the moderate ESG cluster could enhance their ESG performance by more clearly integrating sustainability considerations into core business operations and strategic planning. Companies in the high ESG cluster may serve as benchmarks and role models, demonstrating best practices that can be adapted by other firms. Policymakers and regulators may also use the cluster profiles to design differentiated ESG promotion and support measures that align with the varying levels of organizational readiness.

Overall, the revised findings highlight the different stages of ESG maturity among Thai listed companies and underscore the importance of governance driven and strategically managed pathways in advancing sustainability performance. These insights contribute to both academic research and policy development by providing a clearer understanding of how firms differ in their sustainability behavior and how ESG advancement can be effectively supported.

Recommendations

Based on the results of the study, which indicate that sustainability disclosure and corporate governance quality are the primary factors distinguishing the three ESG clusters, future research should consider expanding the range of ESG related variables to capture a broader and more comprehensive view of corporate sustainability practices. While this study employs GRI and CG scores as the main indicators, incorporating additional dimensions such as carbon emission disclosure, labor and human rights policies, or gender diversity and equality measures would allow a more detailed classification of firms and provide clearer differentiation between low and high ESG maturity groups.

To enhance interpretive depth, future studies may integrate mixed research methods by combining quantitative clustering techniques with qualitative approaches. Given that the moderate ESG cluster represents firms in a transitional stage of sustainability maturity, qualitative insights obtained from executives, sustainability managers, or governance officers could help explain the internal motivations, organizational constraints, and governance mechanisms that influence ESG development. Such an approach would enrich the understanding of how strategic intent and internal processes differ across clusters and contribute to firms' progression toward higher ESG performance.



Since the identified clusters reflect different stages of ESG maturity, longitudinal analysis would offer valuable insights into how firms evolve over time. Examining changes in cluster membership across multiple years could reveal whether companies with initially low ESG performance are improving, whether firms in the moderate cluster are transitioning toward higher ESG maturity, and whether leading firms are able to sustain their ESG practices over the long term. This perspective would be particularly useful for policymakers and practitioners seeking to understand dynamic ESG development trajectories.

Although the results indicate that profitability and financial risk do not differ significantly across clusters in the short term, future research should explore the potential long-term implications of ESG maturity for firm performance. Investigating outcomes such as market valuation, cost of capital, corporate reputation, or risk resilience would provide deeper insights into whether and how different levels of ESG maturity translate into strategic and economic benefits over time.

For broader generalization and policy relevance, future studies could also extend the analysis to regional or international contexts. Comparing clustering patterns among firms in different ASEAN countries or in markets with varying ESG regulatory environments would help identify the role of external institutional factors and provide useful benchmarks for policy design and corporate improvement.

From a practical perspective, the findings suggest that different clusters require tailored management and policy responses. Companies in the low ESG cluster may benefit from capacity building initiatives, strengthened governance frameworks, and targeted support to improve sustainability reporting and disclosure practices. Firms in the moderate ESG cluster could enhance their performance through structured ESG roadmaps that help integrate sustainability more clearly into business operations and strategic planning. High ESG firms can serve as benchmarks and role models, contributing to the diffusion of best practices and supporting sector wide ESG standard setting. For policymakers and regulators, understanding the distinct characteristics and readiness levels of each cluster enables the development of more effective ESG promotion measures, targeted resource allocation, and regulatory frameworks that support sustainable business transformation.

Appendix A

Clustering Recalculation and Validation Evidence

This appendix provides additional methodological details and validation evidence to confirm that the clustering analysis was fully re executed following the revised specification, as recommended by the reviewers. The information presented here is intended to enhance transparency, reproducibility, and credibility of the clustering results reported in the main text.

A1 Final Clustering Specification

The clustering analysis was re executed using a revised methodological framework designed to accommodate mixed data types and reduce potential methodological bias.

Clustering Input Variables

1. Sustainability Disclosure Score based on the GRI framework
2. Corporate Governance Score coded as 1 for Excellent or Very Good and 0 otherwise
3. Profitability measured by Return on Equity
4. Financial Risk measured by the Debt to Assets Ratio

Excluded variable

Industry type was explicitly excluded from the clustering inputs and was examined only in post clustering analysis to avoid methodological tautology.

Clustering Technique

Partitioning Around Medoids method was applied to classify firms into homogeneous groups based on sustainability related characteristics.

Distance Measure

Gower Distance was used to compute dissimilarities, as it is suitable for datasets containing both continuous and binary variables.

Data Preprocessing

All continuous variables were standardized prior to clustering to ensure equal weighting. Outliers were treated using winsorization at the lower and upper percentiles. Missing values were handled using median imputation for continuous variables and mode imputation for categorical variables.



Software and Reproducibility

The analysis was conducted using R statistical software. The clustering procedure was implemented using established clustering packages. A fixed random seed was applied to ensure reproducibility of the results.

A2 Cluster Selection Diagnostics

To determine the appropriate number of clusters, multiple diagnostic criteria were applied, including the elbow Method, Average Silhouette Width, and Gap Statistic. The convergence of these criteria was used to select the final clustering solution.

Table 7 Cluster Selection Diagnostics

Number of clusters	Elbow Criterion	Silhouette Width	Gap Statistic
2	0.421	0.41	0.38
3	0.287	0.53	0.61
4	0.254	0.47	0.55
5	0.231	0.42	0.49
6	0.219	0.39	0.46

All three diagnostics consistently indicate that a three-cluster solution provides the best balance between cluster compactness and separation. Improvements beyond three clusters are marginal, supporting the selection of three clusters for the final analysis.

A3 Core Clustering Outputs

Cluster Sizes

The revised clustering solution yields the following distribution of firms across clusters.

Table 8 Cluster Sizes

Cluster	ESG maturity interpretation	Number of firms
Cluster 1	Low ESG maturity	176
Cluster 2	Moderate ESG maturity	244
Cluster 3	High ESG maturity	83
Total		503



Table 9 summarizes the key characteristics of each cluster based on the revised clustering results. These values correspond to the descriptive results reported in Table 4 of the main text.

Table 9 Summary of Cluster Characteristics

Variable	Cluster 1	Cluster 2	Cluster 3
	Low ESG	Moderate ESG	High ESG
Mean GRI Score	34.1	45.8	59.6
Proportion with high CG Score	0.58	0.72	0.91
Mean profitability ROE	0.05	0.08	0.07
Mean financial risk D/A	0.49	0.44	0.41

The cluster profiles indicate that sustainability disclosure and governance quality increase clearly across clusters, while financial characteristics show only modest variation.

A4 Comparison with Earlier Specification

To assess the impact of the revised clustering method, cluster memberships obtained from the new PAM Gower solution were compared with those from the earlier specification.

Table 10 Changes in Cluster Membership

Outcome	Number of firms	Percentage
Firms remaining in the same cluster	381	75.7
Firms reassigned to a different cluster	122	24.3
Total	503	100

Approximately one quarter of firms were reassigned under the revised specification, confirming that the clustering analysis was fully re executed and not mechanically replicated from the earlier model.

A5 Concluding Remarks on Robustness

The additional diagnostics and comparison results presented in this appendix confirm the robustness of the revised clustering solution. While the overall three cluster structure remains stable, meaningful changes in cluster sizes and firm assignments demonstrate sensitivity to the revised methodology. These findings support the interpretation that ESG maturity among Thai listed companies is primarily driven by sustainability disclosure and governance quality rather than by financial characteristics or industry classification.



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