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Sustainability-Linked Finance: Bridging Nature Disclosure Gaps in Southeast Asia

Jose L. Resendiz[a], Nicola Ranger[b], Johan Sulaeman[c], David C. Broadstock[c]

ABSTRACT *This paper examines Southeast Asia's sustainability-linked finance (SLF) market—an emerging class of instruments that tie borrowing costs to sustainability outcomes—and its treatment of risks such as deforestation and biodiversity loss. Using market analysis and a retrieval-augmented generation approach to extract corporate-report data, we assess the alignment between Sustainability Performance Targets (SPTs), firms' disclosed KPIs and the TNFD's global guidance across 2017-2024, covering over 200 deals worth nearly USD 20 billion. Companies frequently report performance that exceeds their SPTs; although this appears positive, the excess metrics are not subject to SPT-level verification, weakening accountability and increasing greenwashing risk. We find that over 60% of nature-related KPIs—especially water and waste—are omitted from SPTs, exposing inconsistencies between what firms monitor and what their financiers reward. Sustainability-linked loans dominate activity, led by Singapore, Thailand and Indonesia, while other SLF instruments lag behind. We recommend aligning disclosures with SLF SPTs using emerging standards, accrediting financial institutions that act as sustainability coordinators to vet SPTs in the SLF deals, and introducing fiscal incentives like tax exemptions and credit guarantees to mobilise investment and reduce greenwashing risks.* (*JEL* G18, Q56, G32, K32, Q51)

Keywords: nature-related risks, corporate reporting, sustainability-linked finance, key performance indicators

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Key Policy Insights

- Financial institutions must standardise nature-related metrics in SLF deals by adopting global frameworks, closing disclosure gaps while remaining manageable for participants.
- Lead arrangers and underwriters should be accredited as independent sustainability coordinators to vet and approve SLF targets, bolstering credibility and preventing conflicts of interest.
- Financial regulators should work to align corporate sustainability KPIs with SLF targets and could consider introducing penalties for non-compliance, to encourage consistent progress towards nature-related goals.
- Treasury and fiscal authorities ought to introduce targeted incentives—tax exemptions and credit guarantees—to lower financing costs and mobilise private investment in nature-positive projects.

1. Introduction

Global economic stability faces growing threats from nature-related risks, including deforestation, biodiversity loss and water scarcity, with potentially substantial economic costs (Ranger et al., 2023). Southeast Asia (SEA) is a particular ecological hotspot—its tropical rainforests and freshwater systems harbour immense biodiversity yet are under acute pressure from land-use change and water stress, making any ecosystem collapse there disproportionately costly. For instance, if critical ecosystems collapse in Southeast Asian countries, their combined GDP in 2030 could be nearly 7% lower than under stable conditions (Johnson, 2021). These risks materialise physically, as demonstrated by Malaysia's 2023 floods, which displaced over 50,000 people (Ng, 2023), and Indonesia's 19% forest loss between 2001 and 2023, causing up to USD 16.8bn in flood damage from 2003 to 2018 (CRED, 2024; GFW, 2024). Transition risks are also emerging, driven by growing consumer demand for sustainable practices—e.g., for palm oil producers in Indonesia, Malaysia and Thailand that produce 88% of the world's supply (USDA, 2024). Additionally, systemic risks threaten food security through disrupted ecosystems (Alencar et al., 2023; Eddy et al., 2021). Amid these challenges, innovative financial tools, such as sustainability-linked finance (SLF), offer promising solutions to mobilise corporate finance for nature. SLF ties borrowing costs to sustainability performance targets (SPTs), for example, reducing interest rates for companies that restore critical habitats, thus helping mitigate risks and promoting conservation (ACMF, 2022; ICMA, 2023).

Despite growing interest in sustainable finance, significant gaps persist in addressing nature-related financial risks. Existing SLF frameworks heavily emphasise carbon emissions, frequently overlooking equally critical factors such as biodiversity loss and water scarcity. This narrow focus is compounded by the absence of regional guidelines for nature-related key performance indicators (KPIs), resulting in inconsistent corporate reporting practices. Furthermore, comprehensive frameworks such as the Taskforce on Nature-related Financial Disclosures (TNFD) remain in early stages of adoption (Tumay, 2024). Academic research underscores persistent challenges in accurately assessing the financial impacts of these nature-related risks and achieving cross-industry comparability. These difficulties are further intensified by limited corporate awareness, insufficient data availability, and inadequate organisational capacities (Smith et al., 2024).

This paper offers a first-of-its-kind analysis of the SLF market in SEA, focusing on nature-related risks and opportunities. SEA is selected because its rapidly evolving financial systems—including dynamic bond markets, emerging SLF guidelines across national regulators, and active development finance institutions—provide a diverse and high-growth context in which to assess how nature-linked KPIs are integrated into debt instruments. Our paper examines the integration of nature-related KPIs in SLF instruments and corporate sustainability reports, evaluating their alignment with reporting standards (e.g., TNFD). The study employs a two-part methodology: (1) a market landscape analysis assessing transaction volumes, cumulative debt and the role of financial institutions acting as sustainability coordinators; and (2) a retrieval-augmented generation (RAG) approach to systematically extract and classify KPIs from official corporate reports, enabling analysis of two distinct gap levels: the Instrumental Gap (metrics in SLF deals vs. corporate disclosures) and the Disclosure Gap (corporate disclosures vs. international standards) (see Appendices A and B).

Our findings reveal that SEA's sustainable finance market is rapidly expanding, driven predominantly by sustainability-linked loans (SLLs), which have overtaken sustainability-linked bonds (SLBs). Syndicated SLLs' issuance surged fivefold between 2017 and 2021, reaching USD 12.49 billion, predominantly in markets such as Singapore, Thailand, and Indonesia. In contrast, other markets, notably Vietnam and Cambodia, lag due to less-developed financial infrastructure. Network analysis of the current market structure reveals that certain key financial institutions function as influential hubs, while overall connectivity remains low—suggesting a fragmented network with diversification among participants. Our analysis indicates that despite the sector's growth, substantial SLF targeting gaps persist—particularly in relation to critical nature-related metrics such as water usage and waste management. Our findings indicate that nearly 60% of nature-related KPIs that are already disclosed in corporate reports are absent from the SPTs in their respective SLF deals, presenting significant opportunities for improved ecological accountability.

Based on our findings, we identify four policy implications for enhancing the transparency, credibility, and scalability of SLF instruments in Southeast Asia. To address observed targeting gaps and bolster ecological accountability, regional standardisation of nature-related KPIs, aligned with global frameworks, should be coordinated by regional bodies such as the ASEAN Capital Markets Forum. Given the cross-border nature of capital markets, a regional governance framework is vital for ensuring consistent, tradable, and interoperable SLF solutions across jurisdictions. Strengthening alignment between the KPIs in corporate sustainability reports and the SPTs in SLF deals—supported by penalty mechanisms inspired by international models like the EU Green Bond Regulation—would reinforce accountability and credibility. Accreditation requirements for sustainability coordinators—financial institutions responsible for advising issuers on the selection of SPTs—should include independent certification and third-party verification to mitigate conflicts of interest and enhance consistency. Finally, tailoring European- and US-style tax incentives and blended risk-sharing instruments to Southeast Asian realities would not only compress financing costs for nature-positive projects but, by signalling alignment with global green-finance norms, position the region to capture a larger share of internationally mobile capital—thereby reinforcing a coordinated regional response to nature-related financial risks.

The remainder of the paper is structured as follows: Section 2 summarises the methodology, with further details provided in the appendices. Section 3 presents results from our market analysis and reviews disclosure and instrumental gaps. Section 4 discusses policy implications. Section 5 concludes by highlighting contributions and areas for future research.

2. Methodology

This study employs a multi-method analytical framework to assess Southeast Asia's SLF market, integrating quantitative market trend analysis, network theory, natural language processing, and compliance gap analysis. The methodology evaluates structural market dynamics, sectoral participation, KPI alignment, and reporting discrepancies, leveraging transactional data, corporate disclosures, and international sustainability frameworks.

Market landscape: The market landscape was assessed using transactional data from Bloomberg (2017–2024) and Environmental Finance (2024), focusing on issuance volumes, deal sizes, and regional distributions of SLLs and SLBs. Comparative analysis between SEA and global markets was conducted to evaluate growth trajectories, with metrics such as year-over-year (YoY) issuance values, deal counts, and sectoral contributions. Sectoral activity was categorised using the Sustainable Industry Classification System (SICS), identifying dominant industries (e.g., Infrastructure at 35% of total market activity) and regional concentrations (e.g., Indonesia, Thailand, Singapore). Volatility trends were analysed through time-series decomposition, isolating cyclical fluctuations linked to macroeconomic factors (e.g., inflation, interest rates).

Network analysis supplemented this by modelling transactional relationships between corporations and financial institutions as a bipartite graph, where nodes represent entities and edges denote SLF deals. Centrality measures—Degree, Eigenvector, Betweenness, and Closeness—were computed to quantify the influence of financial institutions (e.g., United Overseas Bank) acting as sustainability coordinators (Appendix A). The Girvan-Newman algorithm partitioned the network into sector-specific clusters (e.g., Infrastructure, Food & Beverage), with modularity scores evaluating community cohesion (Girvan & Newman, 2002). Temporal subgraphs tracked structural shifts, including declining network density and rising average path length reflecting market decentralisation (Appendix A).

KPI extraction and classification: Nature-related KPIs were extracted from the official corporate reports of 60 firms and mapped to 111 SLF deals (including both bonds and loans) using a Retrieval Augmented Generation (RAG) pipeline. Text was parsed from PDFs using PyPDF2, segmented into 512-token chunks, and embedded into high-dimensional vectors via OpenAIEmbeddings. These vectors were indexed in a FAISS database for semantic similarity retrieval, with queries augmented using Sustainability Accounting Standards Board (SASB)-aligned metrics (e.g., greenhouse gas emissions) to enhance precision (Appendix B). KPIs were classified by industry materiality using the Sustainability Accounting Standards Board's

(SASB) framework, mapping themes such as energy efficiency and water management. The ENCORE tool and the Taskforce on Nature-related Financial Disclosures (TNFD) taxonomy were further used to categorise KPIs according to their association with impacts (e.g., pollution), dependencies (e.g., water scarcity), and strategic attributes (e.g., policy alignment) (Appendix C).

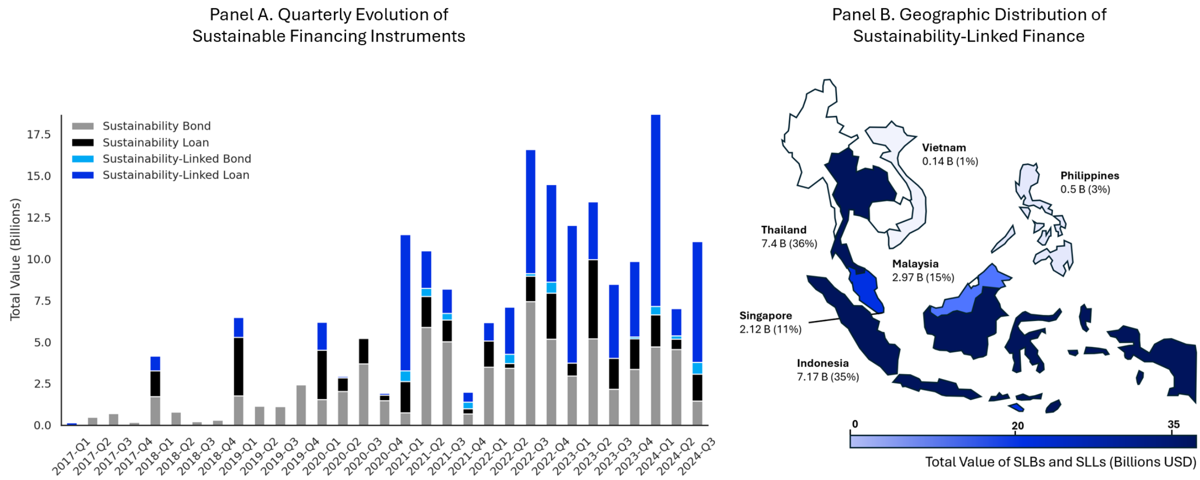
Gap analysis: Gap analysis evaluates two levels of misalignment. The Instrumental Gap measures differences between sustainability targets in Sustainability-Linked Finance (SLF) deals and metrics disclosed in corporate reports. The Disclosure Gap compares corporate disclosures against international standards (e.g., TNFD and ENCORE). Two indices—Impact Gap (environmental harm) and Dependencies Gap (resource reliance)—offer a nuanced view of the Instrumental Gap for SLF targets. Missing KPIs were normalised on a 0–1 scale. Kernel Density Estimates (KDEs) visualise compliance distributions (Appendix D). Pearson correlations tested relationships between financial institutions' network centrality (e.g., Closeness Centrality) and these gaps.

3. Results and Discussion

3.1 *Market Landscape*

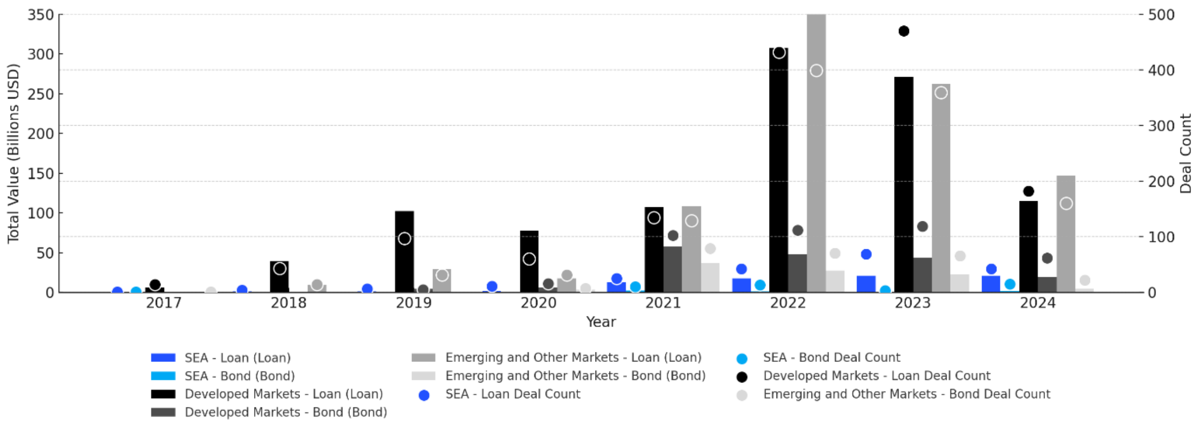
Southeast Asia’s sustainable finance landscape is experiencing a dynamic shift, as SLLs have established a robust growth trend, becoming the dominant instrument, whereas SLBs have yet to demonstrate a clear trajectory of growth (see Figure 1). Between 2017 and 2021, syndicated SLL issuance grew five-fold, reaching USD 12.49 billion in 2021, with an average deal size of approximately USD 377 million and peak issuance at USD 3.7 billion. By comparison, SLBs averaged USD 117 million per deal, peaking at USD 498.72 million. This growth is largely driven by infrastructure projects and sustainability commitments in sectors such as food, beverage, and finance, particularly in more developed financial markets within the region like Singapore (USD 2.13 billion), and to a lesser extent Thailand (USD 7.24 billion) and Indonesia (USD 7.17 billion). Meanwhile, emerging markets such as Cambodia and Vietnam lag behind due to evolving financial systems and less-developed capital markets (WFE, 2024). The comparison in Figure 1 considers sustainability bonds, including green bonds, and sustainability loans, including green loans, as defined in the figure notes.

FIGURE 1. Sustainable Finance Market in SEA (2017-2024)



Source: Environmental Finance (2024) and Bloomberg (2024).
Note: Sustainability bonds and loans are financing tools earmarked for environmental and social impact projects, with the use of proceeds directed exclusively to initiatives like renewable energy or social infrastructure. These labels include Green Bonds, Green Loans, Social Bonds, and Sustainability Bonds, with Green Bonds and Loans prominently funding climate and environmental efforts.

FIGURE 2. Sustainability-Linked Finance Growth: Comparative Analysis of Total Value and Deal Count in Southeast Asia vs. Global Markets

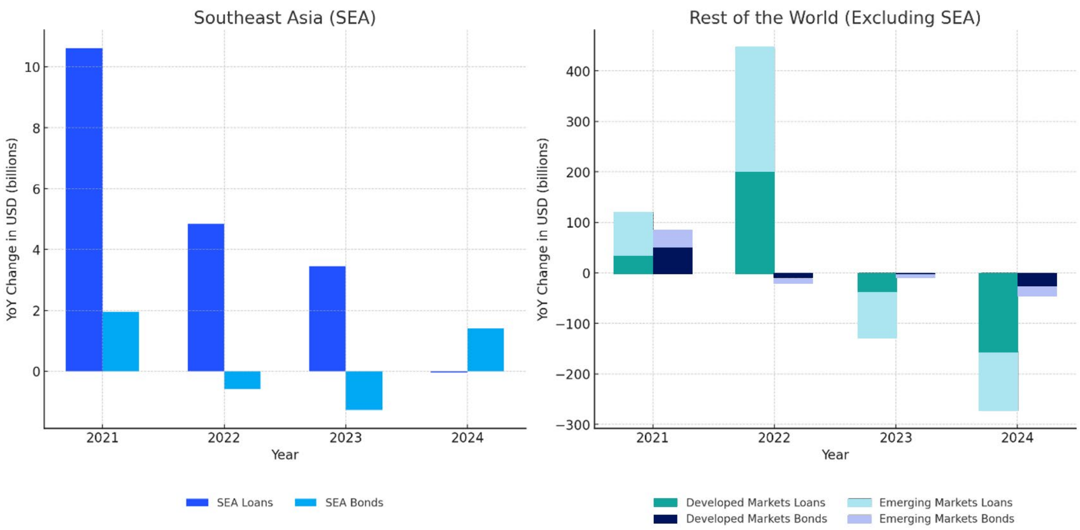


Source: Environmental Finance (2024) and Bloomberg (2024).

Figure 2 illustrates Southeast Asia's growing prominence in SLLs, though issuance values still trail developed markets. SEA maintains a steady deal count, indicating resilience. However, SLBs remain underutilised, partly due to fragmented and less mature regulatory frameworks shaped by diverse local economic conditions and capacities. Strengthening these frameworks and aligning with international best practices could boost SLB issuance, diversify capital inflows, and enhance SEA's position in global sustainable finance.

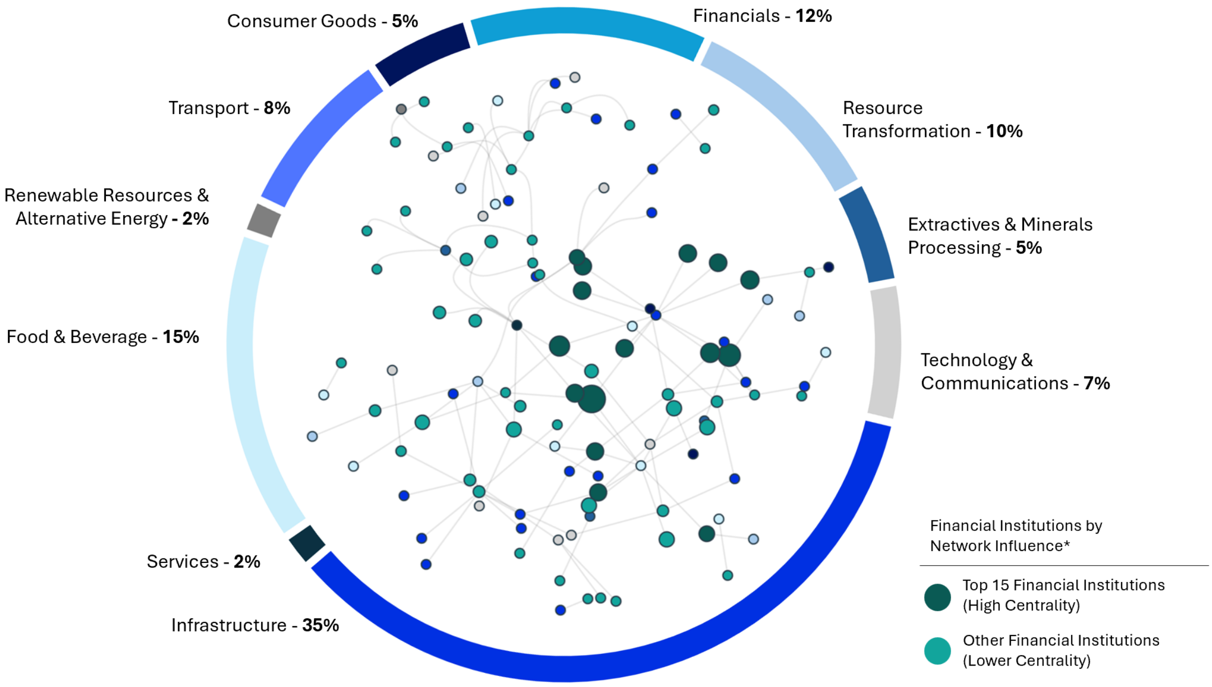
As shown in Figure 3, Southeast Asia's SLF market has experienced notable uncertainty, with SLBs surging by nearly USD 2 billion in year-over-year growth in 2021, then declining by 2023 under the weight of global economic headwinds such as inflation and higher interest rates. A modest uptick in 2024 suggests resilience, although the pronounced fluctuations—reflected in the boom-bust cycle—emphasise the region's need for stronger regulatory frameworks and incentives to stabilise investor confidence. In contrast, markets outside SEA do not exhibit a similar recovery in SLB issuance, likely due to prolonged economic challenges, saturation in sustainable finance markets, or stricter monetary policies. By adopting best practices from these markets and enhancing transparency can further strengthen SEA's resilience and global sustainable finance position.

FIGURE 3. Sustainability-linked Finance: Year-over-year Change in USD (Billions)



Source: Environmental Finance (2024) and Bloomberg (2024).

FIGURE 4. Market Participants Network in the SLF Market in SEA: Capital Providers and Counterparties by Sector

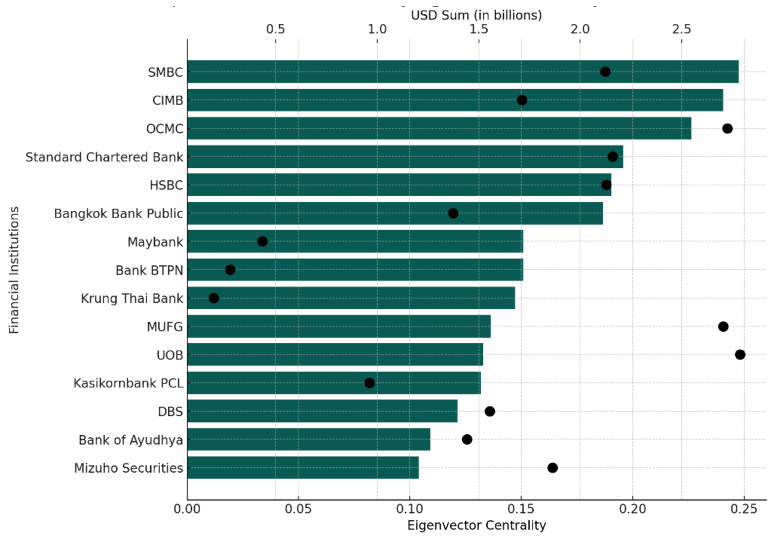


Source: Environmental Finance (2024).
Note: This bipartite network represents the relationships between financial institutions (nodes) and corporations (nodes) through sustainability-linked finance (SLF) deals (edges), where each edge indicates a transactional partnership in the SLF market. All nodes are displayed with a standard size, except for the top 15 most influential financial institutions, shown in dark green and sized according to their influence using the eigenvector centrality measure. This measure indicates how well-connected each institution is to other influential nodes in the network; see Appendix A for detailed methodology.

The combined analysis of SLL and SLB markets in Southeast Asia (SEA), totalling nearly USD 20 billion in deals, reveals that Infrastructure dominates at 35% (around USD 7 billion), underscoring the region's strategic focus on sustainable infrastructure projects—particularly in Indonesia, Malaysia, and Thailand—as shown in Figure 4. Key financial institutions such as United Overseas Bank and Bangkok Bank Public frequently serve as sustainability coordinators, guiding borrowers and lenders in structuring deals with appropriate KPIs and aligning with market standards (BBVA, 2019). The Food and Beverage sector follows at 15% (approximately USD 3 billion), reflecting commitments to circular economy and ethical supply chains in markets like Thailand and Vietnam, while the Financials sector accounts for 12%, driven by growing demand for sustainable finance products. Resource Transformation and Transportation represent 10% and 8% of the market, respectively, and Extractives & Minerals Processing comprises around 10% (USD 2 billion), largely concentrated in Indonesia and the Philippines to mitigate environmental impacts from resource extraction. Meanwhile, Renewable Resources & Alternative Energy stands at about 7% (USD 1.4 billion), led by significant solar and wind projects in Vietnam and the Philippines. Other sectors—such as

Technology & Communications at 7%—further highlight the breadth of SEA's sustainable finance activity, with certain financial institutions (e.g., Mizuho and CIMB) displaying high interconnectedness across multiple industries. Overall, this sectoral distribution underscores SEA's emphasis on high-impact areas essential for sustainability and climate adaptation, with financial institutions playing pivotal roles in mobilising and coordinating capital for transformative projects.

FIGURE 5. Top 15 Financial Institutions in Southeast Asia's SLF Market: Relationship between Transaction Volume and Network Centrality



Source: Authors' calculation based on Bloomberg (2024).
Note: Eigenvector centrality (dots) reflects each institution's network importance based on both direct connections and the influence of connected nodes (see Appendix A for details). Transaction volume in USD billions (bars) represents the aggregated total debt facilitated by each institution across all deals in which they served as sustainability coordinators or lead arrangers.

Understanding the network structure and connectivity of financial institutions is essential for comprehensively analysing Southeast Asia's SLF market, as these institutions serve as key actors linking corporate borrowers, investors, and sustainability objectives. Our analysis employed network theory, utilising centrality measures (see Appendix A), to uncover patterns of influence, identify central institutions driving market trends, and reveal sector-specific clusters, enabling targeted and effective policy interventions. The analysis identified institutions with high eigenvector centrality, such as SMBC and CIMB, as influential hubs coordinating SLF transactions. Community detection revealed sector-specific clusters, particularly in Infrastructure (Table A2). These clusters highlight opportunities to strengthen targeted industry partnerships and sustainability initiatives.

Network density sharply decreased from 0.67 in 2017 to 0.05 in 2023 (Table A3), reflecting substantial fragmentation towards decentralisation, likely driven by COVID-19 disruptions and the emergence of more independent institutions. Future stability could influence whether connectivity rebounds, impacting SLF market evolution. Temporal analysis further demonstrated that as the SLF market expanded, the network became sparser and less connected, consistent with broader participation in regional sustainability goals. As shown in Figure 5, the top 15 financial institutions collectively manage over USD 4 billion in SLBs and SLLs, with individual portfolios ranging from USD 200 million to USD 600 million. These high-centrality institutions, serving as key sustainability coordinators or lead arrangers, concentrate heavily on critical sectors such as Infrastructure and Renewable Energy—with Infrastructure alone accounting for over 40% of the total debt facilitated—while also significantly engaging in Resource Transformation and Consumer Goods.

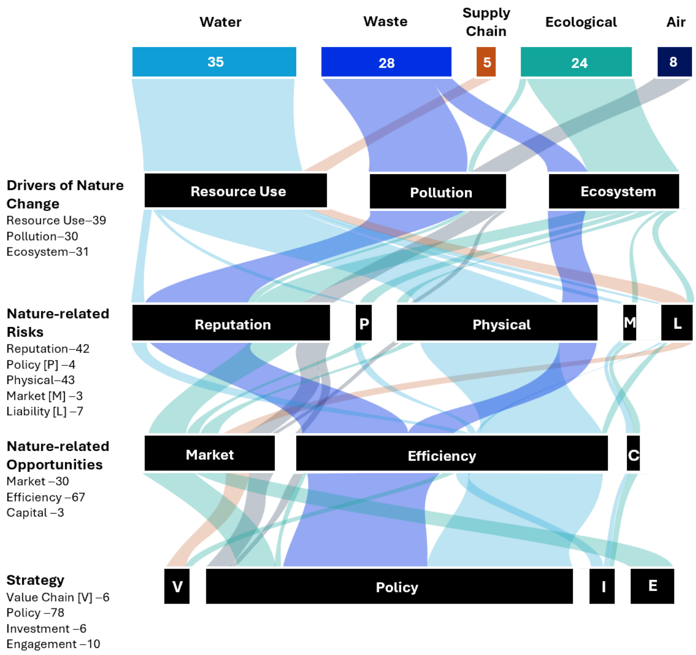
3.2 *Corporate Reports' Metrics and SLF Targets Classification*

This section presents a cross-classification analysis of nature-related KPIs disclosed in corporate sustainability reports and those explicitly included as targets SLF deals within Southeast Asia. KPIs were categorised by industry-specific material topics defined by the SASB and mapped across the dimensions of the TNFD framework. This combined SASB-TNFD approach offers a structured overview of corporate reporting practices and SLF target-setting, laying the foundation for the gap analysis presented in the following section (data extraction methodology is detailed in Appendices B and C).

Nature-related KPI disclosure through TNFD lens. Figure 7 shows a classification analysis of nature-related KPIs disclosed among corporate issuers in Southeast Asia's SLF market, revealing key patterns in alignment with the TNFD framework considering four categories (see Figure 7-A): drivers of nature change, nature-related risks and opportunities, and strategy (TNFD, 2022). Drivers. We analysed a total of 273 KPIs extracted from corporate reports (annual and sustainability reports). Our findings indicate that water-KPIs across sectors predominantly focus on resource usage, often neglecting critical dimensions of water pollution and broader ecosystem impacts on aquatic systems, such as rivers, lakes, and oceans, which are vital for sustainable resource management (Roley et al., 2014). Similarly, waste-related KPIs emphasise hazardous waste management to minimise land pollution but inadequately address broader ecosystem considerations, such as soil health management practices (Larkin, 2015). More effective KPIs would incorporate a life-cycle perspective, addressing both hazardous and non-hazardous waste to mitigate pollution impacts across terrestrial and aquatic ecosystems. An integrated approach to pollution and ecosystem health aligns with sustainable development principles, which call for managing cumulative impacts to ensure long-term ecosystem resilience, a necessity for sustaining agrifood and resource transformation industries in the region (Folke et al., 2004).

FIGURE 7. Distribution of Nature-related KPIs Disclosed in Corporate Reports from SEA-SLF Market Participants across TNFD and SASB Categories (%), 2018-Q1 to 2024-Q3

Panel A. Percentage of KPIs Disclosed in Corporate Reports across TNFD Categories and Subcategories



Panel B: Percentage of KPIs Disclosed in Corporate Reports across TNFD and SASB Categories

	Water	Waste	Supply Chain	Ecological	Air
Resource Use	88.3	0.0	11.7	0.0	0.0
Pollution	2.2	66.7	0.0	4.4	26.7
Ecosystem	0.0	27.1	0.0	72.9	0.0
Reputation	7.7	46.2	0.0	30.8	15.4
Policy	16.7	0.0	0.0	83.3	0.0
Physical	66.7	19.7	0.0	10.6	3.0
Market	60.0	0.0	0.0	40.0	0.0
Liability	9.1	0.0	63.6	27.3	0.0
Market	0.0	0.0	15.2	67.4	17.4
Efficiency	50.0	42.2	0.0	3.9	3.9
Capital	60.0	0.0	0.0	40.0	0.0
Value Chain	0.0	0.0	77.8	22.2	0.0
Policy	39.2	35.8	0.0	15.0	10.0
Investment	77.8	0.0	0.0	22.2	0.0
Engagement	0.0	0.0	0.0	100.0	0.0

All values represent the percentage of KPIs disclosed in corporate reports, calculated as a percentage of the total n=273

Source: Authors' dataset of KPIs extracted from corporate reports (2024).
Note: This figure presents the percentage distribution of nature-related KPIs disclosed in corporate reports across TNFD categories and subcategories in corporate disclosures, based on an analysis of 273 KPIs extracted from corporate reports of market participants in the SEA SLF Market from 2018-Q1 to 2024-Q3. **Panel A** uses a Sankey diagram to visualise the allocation of KPIs from specific nature themes (Water, Waste, Supply Chain, Ecological, Air) across Drivers of Nature Change, Nature-related Risks, Nature-related Opportunities, and Strategic Components. Labels on the left indicate TNFD categories and subcategories, with percentage values showing the percentage of KPIs at each stage. Some subcategories are represented by initials (e.g., P for Policy, M for Market). **Panel B** presents a heatmap showing the percentage of KPIs in each subcategory across nature themes, with darker colours indicating a higher proportion of KPIs within each theme.

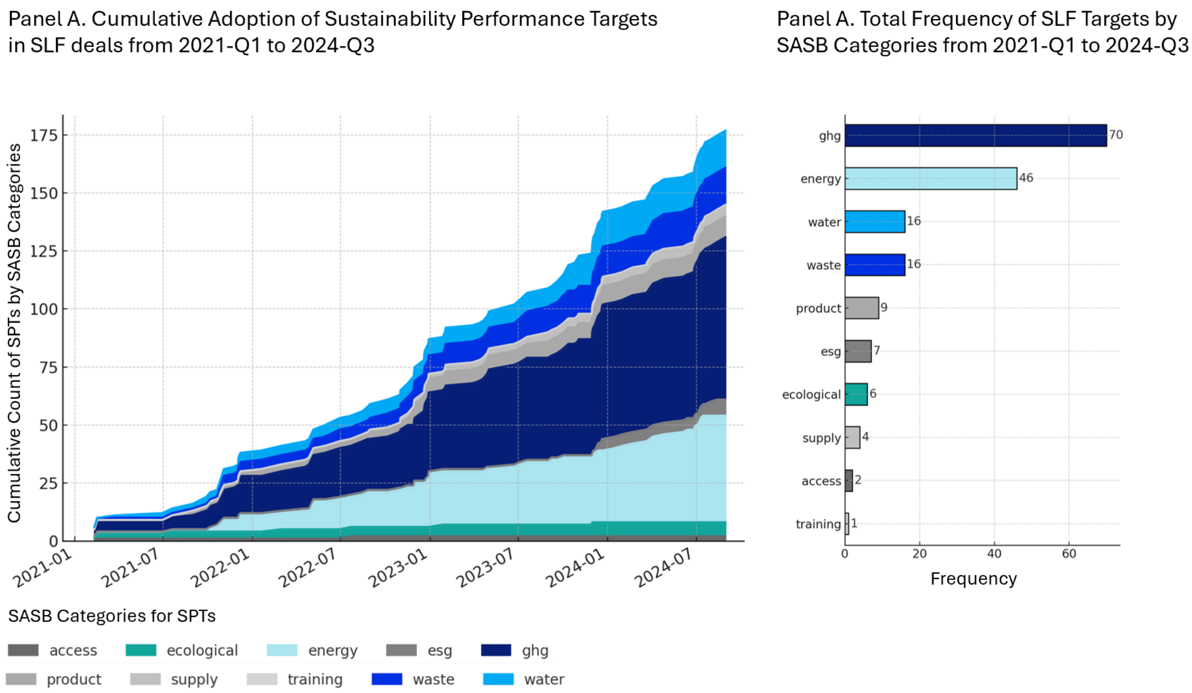
In terms of nature-related risks, physical and reputational risks are the most frequently disclosed, particularly in SEA's Infrastructure and Transportation sectors, where companies emphasise vulnerabilities to extreme weather, water scarcity, and environmental perception. These risks are connected with the region's exposure to climate-related natural disasters, driving corporate awareness of operational threats and long-term reputational impacts, especially in industries reliant on public perception and government support (Beirne et al., 2021). In contrast, regulatory, market, and liability risks are often deemed less relevant for KPIs, except in the agrifood sector, where liability risks are more prominent due to complex, multi-jurisdictional supply chains and accountability pressures (Septiani et al., 2016). However, supply chain transparency remains a significant barrier to accurate risk assessment (CDP, 2023; CISL, 2021), and the region's less stringent regulatory environment, compared to other jurisdictions like the European Union, reduces pressure for detailed environmental disclosures (Cheok, 2023). While the TNFD framework has begun to increase demand for environmental accountability (EY, 2024), most corporations continue to prioritise physical and reputational risks due to their immediate operational and market impacts.

Corporate disclosures reveal that 67% of reported opportunities focus on water and waste management efficiencies, which enhance operational resilience and financial outcomes in resource-scarce regions (Kahiluoto & Kaseva, 2016; Özbuğday et al., 2020; Simionescu et al., 2020). Additionally, 30% target market-driven opportunities tied to higher ESG scores, such as ecological conservation, which can improve bond returns and credit quality (Jang et al., 2020). However, only 3% mention sustainable finance products, despite their potential to reduce capital costs by signalling lower risk profiles (Berrada et al., 2022). Nearly 80% of KPIs remain policy-centric, meaning they mainly reflect corporate policies or stated commitments, such as biodiversity protection policies or general water-use reduction pledges. These KPIs often lack measurable operational targets and show limited integration with value-chain resilience, customer engagement, or investment strategies (MacFarland & Brugger, 2024). Most KPIs focus on natural resource usage and operations in sensitive locations, with minimal attention to certifications, procurement, or customers, except in agrifood sectors. Only 5% are linked to investment opportunities, highlighting a disconnect between policy-driven approaches and business growth strategies. This implies companies may be focusing on general, internal policy KPIs primarily to align quickly with global ESG standards and anticipated regulations, rather than pursuing sustainability as a strategic driver of growth.

Targets in the SEA-SLF Market: In Southeast Asia's SLF market, there is a rising adoption of nature-related SPTs associated with water and waste, which reflects how these countries have leveraged their abundant natural resources to drive resource-intensive industries (Rasiah, 2020). SPTs related to climate mitigation, particularly GHG emissions and energy efficiency, dominate SLF associated targets, aligning with global sustainable finance trends and reflecting an early standards focus on climate mitigation use cases (CBI, 2024a; ICMA, 2023).

According to Figure 6–A, GHG emissions are the most consistently adopted SPT, reflecting mounting pressure on corporations to curb carbon emissions amid international climate action frameworks. For instance, Malaysia targets a 45% reduction in GHG emissions and Singapore aims for net-zero emissions by 2050 (ACE, 2024). This focus on emissions reduction and energy efficiency is particularly pertinent in Southeast Asia, a key player in global supply chains where sectors such as logistics, food processing, and heavy manufacturing can boost competitiveness and profitability (Marchi et al., 2018). Supporting this emphasis, debt linked to GHG reduction targets totals \$12.54 billion and \$6.94 billion for energy efficiency, indicating a strategic shift toward climate mitigation over broader sustainability goals. Meanwhile, the adoptions of natural resource SPTs, with \$1.81 billion tied to water and \$2.50 billion to waste management, underscore a growing commitment to responsible resource use, especially in the agriculture and food processing sectors in Thailand and Vietnam, where sustainable practices are crucial for long-term resilience in water-stressed regions (ASEAN Secretariat, 2023).

FIGURE 6. Southeast Asia's Evolving Priorities in SLF: Nature- and Climate-related SPTs



Source: Environmental Finance (2024) and Bloomberg (2024).

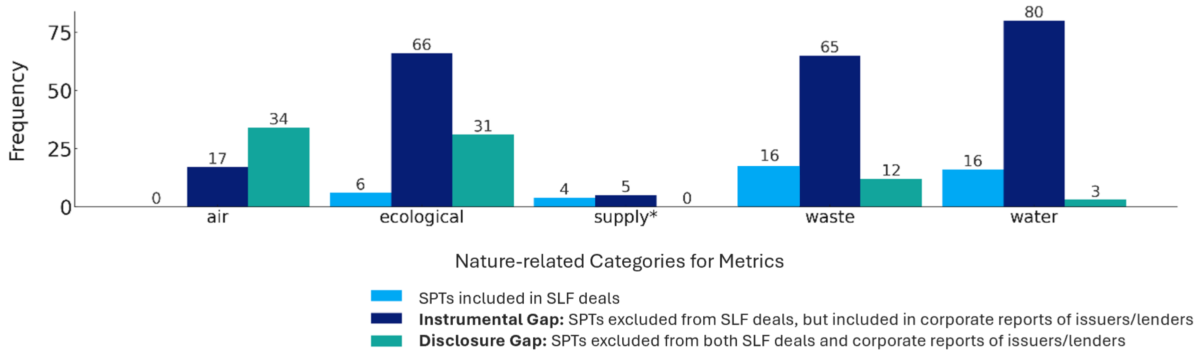
Note: The cumulative disclosure plot starts from 2021, omitting 15 pre-2021 disclosures to highlight recent trends. This approach is suitable as SPTs in SLF are tracked continuously across each deal's tenor, ensuring that disclosed targets remain active. Thus, cumulative representation accurately reflects longitudinal presence of targets, assuming consistent monitoring throughout deal tenors.

3.3 *Gap Analysis and Indices*

Instrumental and Disclosure Gaps: We identify two key reporting gaps in nature-related metrics. The instrumental gap stems from discrepancies between KPIs disclosed in corporate reports and those reflected as SPTs in issuers' or borrowers' SLF deals. The disclosure gap refers to KPIs missing from corporate reports compared to industry-specific standards, as defined by SASB categories, which reflect material risks to enterprise value. Figure 8 illustrates these gaps for SEA-SLF market participants by categorising KPIs into three groups: (1) those incorporated into SLF deals, (2) those disclosed in corporate reports but not incorporated into SLF deals (instrumental gap), and (3) those absent from both SLF deals and corporate reports (disclosure gap), despite their relevance according to SASB materiality criteria.

Assessing gaps using SASB standards provides insights grounded in enterprise value materiality. However, firms may intentionally leave certain SASB-recommended metrics unreported if measurement complexities or costs outweigh perceived business benefits. Recognising these trade-offs is critical when evaluating persistent, yet potentially justified, reporting gaps.

FIGURE 8. Nature-related Metrics Included and Excluded from SLF Deals (SPTs) and Corporate Reports (KPIs), 2018-Q1 to 2024-Q3



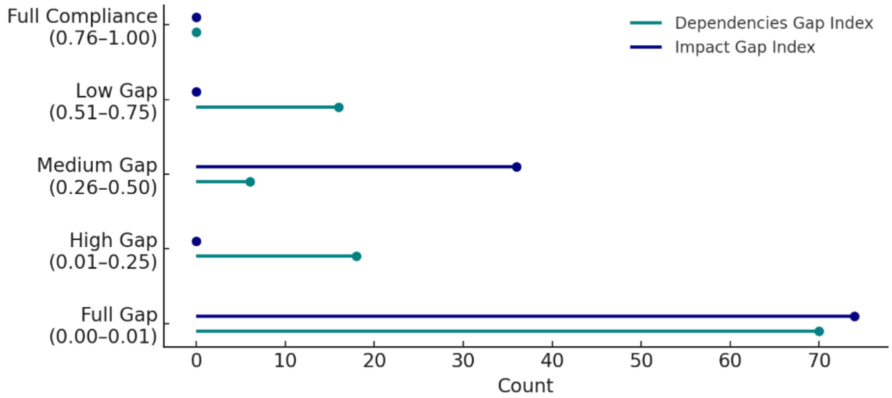
Source: Authors' dataset of KPIs extracted from corporate reports (2024).

The potential to incorporate additional types of SPTs into SLF deals is substantial, indicating a large instrumental gap. Based on historical deal data, issuers could expand current inclusion by nearly sevenfold. Additionally, the disclosure gap is significant, with approximately 30% of nature-related KPIs recommended by SASB standards entirely absent from both SLF deals and corporate reports. This highlights a clear opportunity for issuers to strengthen their SLF issuance by better aligning disclosed KPIs with established frameworks, thereby enhancing transparency and credibility in addressing nature-related risks. Notably, air quality and ecological impacts are among the KPIs least frequently incorporated into SLF deals, despite regular disclosure in corporate sustainability reports. For air quality, SASB's materiality framework often excludes KPIs such as air pollution in industries like Real Estate, limiting their inclusion as SPTs. Similarly, ecological impact KPIs commonly measure processes—such as biodiversity assessments or conservation activities—rather than outcomes. Given that SLF instruments typically prioritise outcome-based SPTs (e.g., GHG emissions reduction), integrating these process-based ecological metrics presents challenges for their effective inclusion.

Impacts and Dependencies Gaps Indices: We developed two Gap Indices—Impact and Dependencies—by comparing each SLF deal's published sustainability performance targets against the full suite of ENCORE-specified KPIs and calculating the proportion of those KPIs that go unmentioned. This normalised 0–1 metric supplies a clear, comparable gauge of how comprehensively deals incorporate nature-related disclosure: 1 denotes complete compliance (every recommended KPI is reported), while 0 indicates total non-compliance (no KPIs disclosed). Applied to 110 SLF transactions in Southeast Asia, the results reveal that most deals cluster at the low-compliance end of the spectrum, with nearly all impact KPIs (pollution, biodiversity loss) omitted and only marginal uptake of dependency metrics (water use, material sourcing). Detailed methodology is provided in Appendix D.

Stratifying deals into five gap categories—full gap (0.00–0.01), high gap (0.01–0.25), medium gap (0.26–0.50), low gap (0.51–0.75) and full compliance (0.76–1.00)—reveals that 74 transactions fall into full gap for impact KPIs and 70 into full gap for dependency KPIs. Notably, fourteen deals occupy the medium gap band for impacts; these tend to disclose the more readily quantifiable indicators, principally water-use metrics and waste-management figures, with only a minority reporting broader ecological measures such as habitat disturbance or emissions intensity. In contrast, the dependencies index shows a more even distribution into the high gap and low gap bands, driven largely by reporting of water consumption, energy use and material-sourcing KPIs under existing corporate and regulatory regimes. Together, these patterns underscore the practical challenges of integrating ENCORE's full suite of impact KPIs into SLF frameworks and point to the need for harmonised methodologies and targeted incentives to promote comprehensive nature-related disclosure.

FIGURE 9. Gap Indices for Nature-related Impacts and Dependencies



Note: This chart shows the number of sustainability-linked financing (SLF) deals falling into five compliance ranges for the Impact and Dependencies Gap Indices. Each "stem" represents the count of deals whose Gap Index—the proportion of ENCORE-specified KPIs missing from their disclosures—falls within a given interval (0.00–0.01, 0.01–0.25, 0.26–0.50, 0.51–0.75, 0.76–1.00). A longer stem indicates more deals in that range. The teal markers and lines correspond to the Dependencies Gap Index, and the navy markers and lines to the Impact Gap Index. This visualisation makes it easy to compare how many SLF deals achieve full compliance versus those with large KPI-disclosure gaps, offering insight into ENCORE alignment across Southeast Asian transactions.

Lastly, we assessed whether different centrality measures for financial institutions—specifically betweenness, closeness, degree, and eigenvector centrality—correlate with the nature-related disclosure gap indexes (merging dependencies and impacts) of the corporations they finance. By examining 38 financial institutions acting as sustainability coordinators and 60 SLF issuers, we calculated each centrality measure to capture various dimensions of influence within the network. The correlation between closeness centrality and the gap index is 0.35, the highest among all centrality measures, with a statistically significant p-value of 0.03. This result implies a moderate positive relationship between Closeness Centrality and the gap index, suggesting that institutions with shorter average paths to others (i.e., those with high network accessibility) are more likely to have higher gap index scores. This could indicate that accessibility across the network might correlate with less comprehensive sustainability disclosure, possibly because these institutions focus on broad reach rather than in-depth reporting. The other centrality measures show weak, non-significant correlations with the gap index, indicating that influence or connectivity alone does not have a clear relationship with sustainability disclosure. These results imply that factors outside network centrality—such as organisational priorities or regulatory pressures—might play a larger role in shaping disclosure practices.

III. Discussion and Policy Implications

This section outlines key policy recommendations to address the challenges and opportunities identified in Southeast Asia's SLF market. Drawing on our analysis, the proposals aim to enhance transparency, credibility, and scalability of SLF instruments while addressing nature-related risks and disclosure gaps. The recommendations focus on regional standardisation, alignment of corporate and financial disclosures, accreditation of sustainability coordinators, and fiscal incentives to mobilise private investment.

First, drawing on our analysis of Southeast Asia's rapid SLL growth (Figure 1), sectoral concentration in infrastructure (35% of SLF deals; Figure 4), and material gaps in nature-related disclosures (Figures 8–9), we propose that the ASEAN Capital Markets Forum (ACMF) consider adopting regionally standardised nature-related KPIs to be incorporated as SPTs in SLF deals. This builds on emerging regulatory groundwork in ASEAN, such as Singapore's Monetary Authority (MAS) co-convening a pilot of the TNFD beta framework (v0.1) with Global Canopy in 2022 to test nature-risk reporting in palm oil supply chains (Global Canopy, 2022), alongside Malaysia's Bank Negara collaborating with the TNFD Secretariat to develop nature-risk guidance (World Bank & Bank Negara Malaysia, 2022) and Thailand's SEC joining the TNFD Forum to explore biodiversity disclosures (SEC Thailand, 2021). ACMF could mandate sector-specific KPIs—such as "hectares of peatland restored annually" for Indonesian palm oil issuers or "percentage reduction in freshwater withdrawal intensity" for Thai agrifood borrowers—tailored to local ecological priorities. These KPIs should harmonise with TNFD's LEAP methodology and ENCORE's materiality thresholds. Technical input from the Asian Development Bank (ADB)—drawing on its live regional TA pipelines (e.g., TA packages under the ASEAN Catalytic Green Finance Facility) and its performance-based lending/guarantee platforms whose disbursements are tracked through ADB's design-and-monitoring-framework and Strategy-2030 climate-and-nature result indicators (ADB, 2019)—can both harmonise the KPI taxonomy across regulators and hard-wire it into sovereign and corporate SLF covenants. This approach responds to observed risks, such as SLL volatility (Figure 3), which signals investor scepticism toward self-reported KPIs, and the exclusion of

30% of ENCORE-identified nature-related KPIs from SLF deals (Figure 8), which highlights systemic disclosure gaps. However, implementation faces challenges. These include uneven institutional capacities (e.g., Cambodia and Vietnam lagging Singapore and Malaysia), reliance on voluntary corporate action, and the need for robust third-party verification. A phased adoption strategy is recommended, alongside further empirical research to assess the financial materiality of nature-related risks in ASEAN's diverse ecosystems.

Our second recommendation is to strengthen the link between corporate KPIs and SPTs in SLF, alongside a sanction mechanism that clarifies expectations. We propose that regional regulators—such as Malaysia's Securities Commission, Thailand's SEC, or MAS—consider adopting a clear, proportional compliance framework to ensure that SPTs in financial instruments reflect broader nature positive strategies. Derived from our empirical analysis of disclosure gaps, sectoral imbalances, and reporting inconsistencies in Southeast Asia's SLF market, the proposal sets a transitional target of at least 50 % alignment between bond SPTs and corporate disclosure KPIs—a pragmatic benchmark given that some issuers, such as Indonesia's infrastructure-heavy firms, currently disclose only 30–40 % of relevant KPIs. Although no Southeast Asian jurisdiction yet enforces a comprehensive, CSRD-like ESG reporting law—Malaysia is only beginning to align with ISSB standards via its National Sustainability Reporting Framework (SCM, 2024)—existing guidelines (ACMF, 2022) already encourage issuers to use KPIs from annual or sustainability reports and to provide historical data for previously unreported metrics. To support alignment, we draw inspiration from the EU Green Bond Regulation's provisions (European Parliament, 2023)—where fines for mislabelling can reach up to 0.5 % of annual turnover—and suggest adapting a scaled-down version appropriate for Southeast Asia. This approach balances clear expectation-setting with local market realities, without implying that severe penalties are imminent.

Third, ASEAN regulators should boost the credibility of nature-related risk assessments. They can do this by introducing mandatory accreditation for sustainability coordinators, particularly financial institutions serving as lenders or underwriters. Accreditation would require certification in ESG metrics, TNFD principles, and independent verification. This approach mirrors the EU's oversight of Green Bond Second Party Opinion (SPO) providers (European Parliament, 2023). In negotiating and selecting SPTs for sustainability-linked bonds, underwriters acting as sustainability coordinators can draw lessons from SPO best practices by clearly delineating advisory from underwriting roles, employing robust "not an offer" disclaimers, and avoiding detailed discussion of transaction terms in sustainability materials (Franklin et al., 2020). They should also ensure that any KPI-related documents remain separate from formal offering disclosures, harmonise statements for consistency, and carefully consider potential "expert" liability if they are named in offering documents. However, stakeholder consultations remain vital to balance transparency with market efficiency, avoiding excessive burdens on innovation. Regulatory clarity and third-party oversight are essential for maintaining integrity in SLF instruments, although tailored research for ASEAN's diverse markets is still necessary.

Lastly, to meet the policy objective of increasing finance mobilised for nature—reflecting the Kunming-Montreal Global Biodiversity Framework—we recommend a policy framework for scaling up SLF instruments to address nature-related risks in Southeast Asia should integrate targeted fiscal incentives, robust risk-sharing mechanisms, and coordinated regulatory oversight by drawing on specific, proven models from Europe and the United States. National tax authorities and ministries of finance could implement incentives similar to the Netherlands' Green Funds Scheme, which provides retail investors with tax exemptions on interest earned (up to approximately EUR 55,000) and an additional 1.3% income tax reduction, thereby lowering issuance expenses and reducing the overall cost of capital for green projects (OECD, 2020). On the US front, utilising the fiscal framework of tax-exempt municipal bonds—where interest payments are exempt from federal income tax—can lower borrowing costs significantly for state and local governments (CBI, 2024b). Additionally, deploying credit guarantees and subsidised interest-rate schemes, through central banks like the Bank of Thailand and Bangko Sentral ng Pilipinas would serve to de-risk projects with strong environmental metrics and encourage enhanced disclosure practices. Finally, establishing an ASEAN sustainable finance task force would ensure that these fiscal and regulatory measures are harmonised across the region by standardising nature-related disclosures, facilitating cross-border dialogue, and aligning localised tax incentives with broader sustainability targets. This integrated approach—employing precise tax deductions, exemptions, and credit schemes from Europe and the United States—aims to lower the cost of capital, build market liquidity, and facilitate mobilisation of private investment, thereby catalysing the development of a resilient green finance ecosystem throughout SEA.

V. Conclusion

This study provides the first comprehensive analysis of SEA SLF market, addressing critical gaps in integrating nature-related risks into financial instruments. By combining quantitative market analysis, network theory, and a RAG methodology to classify KPIs, we reveal that 60% of nature-related KPIs disclosed in corporate reports are absent from SPTs in SLF deals, highlighting significant opportunities for SLF to facilitate corporate ecological accountability. Our findings underscore the need for harmonising regional frameworks (e.g., ASEAN SLB Standards) with global guidelines like the TNFD to standardise SPTs, improve transparency, and mitigate greenwashing risks. We propose actionable policy measures, including accrediting financial institutions for TNFD compliance, enforcing SPT-alignment penalties, and leveraging fiscal incentives to stabilise market growth. However, the study is subject to several limitations. First, reliance on self-reported corporate disclosures and transactional databases may introduce biases, particularly in emerging markets with limited transparency and inconsistent reporting standards. Second, the analysis is skewed towards infrastructure and agrifood sectors, which may limit its generalisability to other industries. Third, the static nature of the network analysis captures only a snapshot of SLF market dynamics, potentially overlooking evolving relationships and structural shifts over time. Future work should expand sectoral and geographic coverage, develop standardised outcome-based KPIs and SPTs for biodiversity and water scarcity, and test accreditation systems through pilot programmes. These efforts will strengthen the integrity of SLF markets and support SEA's transition to a sustainable, nature-positive economy.

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Appendices

Appendix A. Network Analysis

Objective.—The objective of our network analysis is to evaluate the structural influence of financial institutions in their relationships with corporations by examining both their network centrality and financial transaction volume. Specifically, this study utilises Eigenvector centrality as a measure of node influence in a bipartite network where financial institutions are connected to corporations via SLF deals. The approach is grounded in network theory, focusing on identifying influential nodes and quantifying relational strength within the network (Freeman, 1978).

Data Source.— We use Bloomberg to get the record SLF deals from 2017 to 2024, where each deal connects a corporation, identified by an International Securities Identification Number (ISIN), with one or more financial institutions acting as sustainability coordinator or lead arranger, along with a recorded transaction value (USD). Additionally, we classify each corporation with its corresponding Sustainable Industry Classification System.

Data Source.— To create a bipartite graph, we define two sets of nodes: C, representing issuers or borrowers, and F, representing financial institutions. For each transaction, each corporation $c \in C$ is linked to one or more financial institutions $f \in F$. The sector classification for each corporation is then mapped, providing an attribute used in the final network visualisation. Furthermore, the transaction values (USD) are summed for each financial institution to provide a measure of each institution's total transaction volume, which serves as a complementary indicator to the centrality measures.

Node Types.— This network can be described as a bipartite, undirected graph $G = (V, E)$, where $V = C \cup F$ represents the nodes (corporations and financial institutions) and $E \subseteq C \times F$ denotes the edges, with each edge e_{cf} indicating a transactional relationship between corporation c and financial institution f. Nodes in C (corporations) are assigned sector-based attributes, with color-coded representations for enhanced interpretability. Nodes in F (financial institutions) are represented uniformly in teal to signify their common role in the network structure.

Edges.— The edges E represent undirected connections between corporations and financial institutions. Since no weights were assigned to these edges, each edge is treated as a binary indicator of the presence of a transaction relationship. This approach aligns with traditional bipartite network models, where connections signify co-affiliation or joint participation rather than magnitude (Newman, 2003).

Network Centrality Analysis.— To understand the influence of financial institutions within the network, we employed multiple centrality measures: Degree Centrality, Eigenvector Centrality, Betweenness Centrality, and Closeness Centrality.

- Degree Centrality (C_D): This measure counts the number of direct connections k_i that a node i has to other nodes in the network, defined as $C_D(i) = \frac{k_i}{N-1}$, where N is the total number of nodes. Degree Centrality highlights the most directly connected nodes, indicating institutions with extensive client relationships (Freeman, 1978).
- Eigenvector Centrality (C_E): This measure identifies influential nodes by weighting connections based on the centrality of each node's neighbours. For node i, Eigenvector Centrality is calculated iteratively as $C_E(i) = \frac{1}{\lambda}\sum_j A_{ij}\, C_E(j)$, where λ is the largest eigenvalue of the adjacency matrix A (Bonacich, 1987). Nodes with high scores are not only well-connected but are also connected to other influential nodes.
- Betweenness Centrality (C_B): Betweenness Centrality measures the extent to which a node lies on the shortest paths between other pairs of nodes. For node i, it is calculated as $C_B(i) = \sum_{s\neq i\neq t} \frac{\sigma_{st(i)}}{\sigma_{st}}$, where σ_{st} is the number of shortest paths from node s to t, and $\sigma_{st(i)}$ is the number of those paths passing through i. This centrality identifies brokers or gatekeepers in the network, as proposed by Freeman (1977).
- Closeness Centrality (C_C): This measure calculates the average shortest path distance from a node i to all other reachable nodes, expressed as $C_C(i) = \frac{1}{\sum_j d(i,j)}$, where $d(i,j)$, is the shortest path distance from i to j. Closeness centrality reflects nodes that can quickly access other nodes, indicating highly accessible institutions (Sabidussi, 1966).

TABLE A1. Indicative Centrality Results for Top 15 Influential Financial Institutions in the SEA SLF Market

Financial Institution	C_D	C_B	C_C	C_E
SMBC	0.078947	0.108603	0.325658	0.247603
CIMB	0.092105	0.096699	0.311499	0.240613
OCMC	0.078947	0.110783	0.329401	0.22635
Standard Chartered Bank	0.039474	0.024973	0.301662	0.195685
HSBC	0.078947	0.117283	0.314922	0.190424
Bangkok Bank Public	0.052632	0.060744	0.311499	0.186614
Bank BTPN	0.039474	0.037137	0.283742	0.150954
Maybank	0.039474	0.037137	0.283742	0.150954
Krung Thai Bank	0.026316	0.009534	0.28096	0.147275
MUFG	0.065789	0.045435	0.269088	0.136405
UOB	0.078947	0.099123	0.272932	0.132822
Kasikornbank PCL	0.052632	0.032491	0.259347	0.131866
DBS	0.052632	0.077018	0.270357	0.121348
Bank of Ayudhya	0.052632	0.035762	0.254737	0.109099
Mizuho Securities	0.052632	0.035366	0.257021	0.10396

Community Detection.— Community detection was conducted using the Girvan-Newman algorithm to identify clusters of nodes that are more interconnected within than across the network. The Girvan-Newman algorithm iteratively removes edges with the highest betweenness centrality, dividing the network into separate components until reaching a modularity-based stopping criterion (Girvan & Newman, 2002). Modularity Q is used to evaluate the quality of the division, defined as:

$$Q = \frac{1}{2m}\sum_{ij}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(C_i, C_j)$$

Where m is the total number of edges, k_i and k_j are the degrees of nodes i and j, A_{ij} is the adjacency matrix, and $\delta(C_i, C_j)$ equals 1 if nodes i and j belong to the same community and 0 otherwise. Higher modularity scores indicate a stronger community structure. The Girvan-Newman algorithm identified multiple clusters, each corresponding to distinct financial sectors or regional partnerships. Table A2 summarises the composition of these communities, listing the dominant sectors and the institutions with the most interconnections.

TABLE A2. Community Structure of Financial Institutions and Corporations by Dominant Sector and Central Financial Entity

Group	Dominant Sector	Top Financial Institution (FI)	Entities	
			Corp	FI
1	Infrastructure	CIMB	29	28
2	Infrastructure	UOB	7	3
3	Food & Beverage	ADB	1	1
5	Extractives & Minerals Processing	Korea Investment & Securities	3	3
4	Infrastructure	AmBank	1	1

Network Density and Connectivity Analysis.— Network density, average path length, and clustering coefficient were calculated to assess the connectivity and structure of the network.

- Network Density (D): This is the ratio of actual connections to possible connections in the network, defined as $D = \frac{2m}{N(N-1)}$, where m is the number of edges and N is the number of nodes. Density indicates how interconnected the network is, with values closer to 1 reflecting a highly cohesive structure (Scott, 2017).
- Average Path Length (L): For connected networks, the average path length is the mean shortest path between all pairs of nodes, calculated as $L = \frac{1}{|P|}\sum_{i,j\in P} d(i,j)$, where P is the set of all node pairs, and $d(i,j)$ is the shortest path distance between nodes i and j. For disconnected networks, this is computed for the largest connected component only (Newman, 2010).
- Clustering Coefficient (C): This measure indicates the degree to which nodes cluster together. For a node i, the clustering coefficient C_i is defined as $C_i = \frac{2e_i}{k_i(k_i-1)}$, where e_i is the number of connections between i's neighbours and k_i is the degree of i. The average clustering coefficient provides a global measure of clustering within the network (Watts & Strogatz, 1998).

As shown in Table A3, network density decreased from 0.67 in 2017 to 0.05 in 2023, indicating a trend towards a more distributed structure. Average path length and clustering coefficient values suggest that the network is sparsely connected, with limited clustering.

TABLE A3. Yearly Network Metrics of Sustainability-Linked Finance Network in Southeast Asia (2017–2023): Density, Path Length, and Clustering Coefficient

Year	Network Density	Average Path Length	Average Clustering Coefficient
2017	0.67	1.33	0
2020	0.33	1	0
2021	0.06	2.67	0
2022	0.06	2.94	0
2023	0.05	3.61	0
2024	0.04	3.26	0

Network Density and Connectivity Analysis.—Temporal analysis was conducted to examine changes in network structure over time, using yearly subgraphs. For each year, we created a subgraph G_t and recalculated network density, average path length, and clustering coefficient. This approach allows us to track structural evolution, identifying periods of expansion or contraction in network connectivity. The results, summarized in Table A3, indicate a gradual decrease in network density and an increase in average path length, suggesting a growing, more distributed network over time. The clustering coefficient remained low across all years, consistent with a decentralized structure where institutions do not form tightly knit groups. This trend likely reflects the expansion of the sustainability-linked debt market, as new entrants diversify the network.

Appendix B. Retrieved Augmented Generation

To gather KPIs from corporate reports, we employed a Retrieval Augmented Generation (RAG) approach to identify and extract nature-related KPIs from structured PDF documents. The method combines the strengths of retrieval-based techniques with generative models to improve the relevance and accuracy of the generated outputs. The implementation leverages several Python libraries, including langchain, PyPDF2, FAISS, and pandas, to process the data, perform retrieval, and generate contextually accurate responses.

Data Preparation.—The first step in implementing a RAG model is to prepare the data that will serve as the knowledge base for retrieval. This data is typically unstructured text that needs to be processed and segmented into manageable chunks, which can then be searched efficiently. In our implementation, we start by loading an Excel file containing a list of sample metrics, which are later used to enhance the query. Additionally, we load a PDF document containing the target information. The text is extracted from the PDF using the `PdfReader` class from the PyPDF2 library. To handle the token size constraints of language models, the extracted text is split into smaller, overlapping chunks using the CharacterTextSplitter class from the langchain library. This ensures that each chunk is sufficiently small for processing while maintaining contextual overlap for improved relevance during retrieval.

Embeddings and Vector Store.—Embeddings are numerical representations of text that capture semantic meaning in a vector space. These embeddings enable the retrieval system to find semantically similar text chunks based on the input query. A vector store, such as FAISS (Facebook AI Similarity Search), is used to store and efficiently search through these embeddings. We use the OpenAIEmbeddings class to convert each chunk of text into a high-dimensional vector. These vectors are then stored in a FAISS index, which supports fast and efficient similarity searches. The FAISS index allows the system to quickly retrieve the most relevant text chunks in response to a query.

Query Augmentation.—Query augmentation involves enhancing the initial user query with additional relevant information. This step improves the precision of the retrieval process by making the query more specific and contextually rich. In our case, the query is augmented with a list of sample metrics extracted from the Excel file. These metrics are converted into a string and incorporated into the query, ensuring that the retrieval system focuses on finding text chunks that are specifically related to these metrics.

Retrieval Step.—The retrieval step involves searching the vector store for text chunks that are most similar to the augmented query. The aim is to identify the most relevant pieces of text that contain the information needed to answer the query. Using the similarity_search method from the FAISS vector store, we retrieve the top text chunks that are most similar to the augmented query. These chunks are then passed to the next stage for further processing and response generation.

Generation Step.—After retrieving relevant documents, the generative model synthesises this information to produce a coherent and contextually accurate response. The model is guided by the retrieved documents, allowing it to generate text that is both relevant and informative. We use the load_qa_chain method from the langchain library to load a pre-configured question-answering chain. This chain leverages the retrieved text chunks as input to an OpenAI language model, which then generates the final output in response to the query.

Appendix C. KPIs Classification

Our categorisation approach for sustainability KPIs focuses on industry-specific material topics, nature-related impacts, and dependencies. Our categorisation process leverages frameworks and standards from the International Sustainability Standards Board (ISSB), using the Sustainable Industry Classification System (SICS) from the latest Sustainability Accounting Standards Board (SASB) guidelines, as well as the Exploring Natural Capital Opportunities, Risks, and Exposure (ENCORE) tool and the Taskforce on Nature-related Financial Disclosures (TNFD) metrics guidance (TNFD, 2022). This approach ensures alignment with leading sustainability assessment tools. Below is a step-by-step explanation of the approach:

1. KPI Classification by Industry-Specific Material Topics Using SASB Standards.—The first step in categorising the sustainability KPIs involved using SICS, as outlined in the latest ISSB guidelines, which updated SASB standards in 2024. SASB's industry-specific material topics, grounded in extensive stakeholder input, provide tailored materiality considerations for each industry. In this context, materiality refers to the financial relevance of sustainability topics that could influence an organisation's economic performance over the short, medium, or long term.

We classified KPIs under material topics specific to each industry, selecting only one KPI per topic. This approach was chosen to avoid redundancy, given that some corporations report similar KPI types in various forms. Selecting a single representative KPI per topic enables a streamlined focus on the most relevant and impactful indicators.

2. Nature-Related Material Topics and Definitions.—The SASB standards highlight several nature-related material topics across industries. These are critical for understanding and assessing sustainability impacts across sectors. Each nature-related topic below is tailored by SASB for relevance to specific industries. Our categorisation includes the following topics (labels used in parentheses):

- GHG Emissions (GHG): Refers to the emissions of greenhouse gases from industry operations. Emissions intensity and absolute emissions reductions are measured based on industry benchmarks.
- Air Quality (Air): Encompasses pollutants affecting local air quality, including nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM).

- Energy Management (Energy): Involves the efficiency and sources of energy use, encompassing both renewable and non-renewable sources as well as energy efficiency measures.
- Water & Wastewater Management (Water): Focuses on water consumption, discharge, and water quality impacts, covering metrics like water intensity and pollution levels in wastewater.
- Waste & Hazardous Materials Management (Waste): Encompasses waste generation, disposal practices, and hazardous material management.
- Ecological Impacts (Ecological): Includes impacts on ecosystems, biodiversity, and habitats, covering areas like land use and conservation practices.
- Supply Chain Management (Supply): Addresses sustainability practices and impacts across supply chains, particularly where raw material sourcing and production involve ecological considerations.

3. Classification by Nature-Related Impacts and Dependencies Using ENCORE.—After categorising KPIs by industry themes, we used the ENCORE tool to classify them by nature-related impacts and dependencies. ENCORE provides a robust framework for understanding how industries interact with natural resources, which is crucial for identifying high-risk exposures. We focused on high-risk impacts or dependencies that pose significant financial risks or opportunities for industries. This process helps prioritise KPIs that reveal material sustainability issues tied to economic performance.

The ENCORE framework emphasises:

- Dependencies: Industries' reliance on natural capital, such as water, land, or biodiversity, which underpins their operations.
- Impacts: The adverse effects that industrial activities can have on ecosystems, potentially leading to regulatory, operational, or reputational risks.

4. Adding Attributes to KPIs Based on TNFD Taxonomy.—To provide a nuanced understanding of nature-related risks and opportunities, we applied a taxonomy based on TNFD categories to each KPI. This classification helps articulate the drivers, risks, opportunities, and strategic considerations associated with each KPI:

- Drivers of Nature Change: Metrics capturing changes in spatial footprint, pollution, resource use, introduction of invasive species, and ecosystem conditions. Example: “Total spatial footprint (km^2)” for land use.
- Nature-Related Risks: Metrics assessing physical risks (e.g., climate impacts), policy risks (e.g., operating area restrictions), liability risks (e.g., clean-up costs), market risks (e.g., loss of access), reputational risks, technology risks, and transition risks associated with shifts to sustainable practices. Example: “Exposure to increased operational costs due to reputational risks.”
- Nature-Related Opportunities: Metrics reflecting market opportunities (e.g., improvements in Environmental, Social, and Governance (ESG) scores), capital access (e.g., green bonds), and efficiency gains (e.g., operational cost savings). Example: “Value of green finance instruments such as sustainability-linked bonds.”
- Strategic Considerations: These include corporate policy commitments, stakeholder engagement on nature issues, investment in nature-related initiatives, and value chain impacts. Example: “Proportion of sites with active engagement on nature-related issues.”

Appendix D. Gap Index

The Gap Index methodology involves constructing a normalised metric for each SLF deal, indicating the proportion of specific KPIs missing in the SLF disclosures relative to the TNFD standards. For each index (Impact and Dependencies), the Gap Index, G_i is defined as:

$$G_i = \frac{\sum_{j=1}^{m} I(S_j \notin R_i)}{m}$$

where:

- G_i represents the Gap Index for SLF deal i.
- $S_j$denotes each KPI specified by ENCORE standards for a given category (Impact or Dependencies).
- R_i is the set of KPIs reported by the corporation for SLF deal i.
- $I(S_j \notin R_i)$ is an indicator function that takes a value of 1 if the KPI S_j is not in the reported set R_i, and 0 otherwise.
- m is the total number of ENCORE-specified KPIs for that category.

The resulting Gap Index ranges from 0 to 1, where 0 denotes full compliance (all TNFD KPIs are reported), and 1 signifies complete non-compliance (no TNFD KPIs are reported). The KDE plots these indices across all deals, allowing for visualization of compliance distribution patterns across the SLF market.

Centrality Measures of Financial Institutions and Gap Index.—The objective of this analysis was to evaluate whether various centrality measures for financial institutions—Betweenness, Closeness, Degree, and Eigenvector centrality—correlate with the nature-related disclosure gap indexes of the corporations they finance. The disclosure gap index consolidates key dimensions related to sustainability, covering both dependencies on and impacts on natural systems, providing a quantitative metric for assessing disclosure comprehensiveness.

For each centrality measure, we computed a correlation coefficient with the disclosure gap index. The statistical significance of each correlation was evaluated using a two-tailed test, with p-values calculated to determine the probability of observing each correlation under the null hypothesis of no relationship.

The highest observed correlation was between Closeness Centrality and the gap index (r=0.35, p=0.03), indicating a moderate positive relationship that was statistically significant. This finding suggests that financial institutions with higher network accessibility, or shorter paths to other nodes, tend to finance corporations with higher disclosure gap indexes. This result implies that institutions with broad access across the network may prioritise reach over in-depth sustainability reporting. The remaining centrality measures—Betweenness, Degree, and Eigenvector—demonstrated weaker, non-significant correlations with the gap index, indicating that influence, connectivity, or status within the network does not strongly predict disclosure comprehensiveness.

Table C1 summarises these correlations, showing that only Closeness Centrality had a statistically significant relationship with the disclosure gap index. This suggests that network accessibility, rather than connectivity or influence, might be a factor linked to lower levels of disclosure, though the reasons for this relationship may extend beyond network characteristics and reflect broader organizational or regulatory factors.

TABLE 1. Correlation between Financial Institutions' Centrality Measures and Gap Indexes

Centrality Measure	Correlation Coefficient (r)	p-value	Significance Level
Betweenness Centrality	0.21	0.205	Not significant
Closeness Centrality	0.22	0.175	Not significant
Degree Centrality	0.35	0.029	Not significant
Eigenvector Centrality	0.26	0.112	Not significant