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2024 Review of DEA in Banking and Finance Towards Greater Sustainability

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ABSTRACT: This paper presents a recent review on Data Envelopment Analysis (DEA) applications in banking and finance. The review is conducted at the end of the year 2024 and is an updated follow up of the unique DEA survey paper by Kumari [1] entitled "Data Envelopment Analysis Recent Applications in Banking Sector: A Survey". This Survey paper focused on the development of DEA applications in the banking sector and covers the period from 2016 to 2019. However, our 2024 review covers all DEA papers in banking and finance until the year 2024. We gathered 104 papers about DEA in banking and finance. Our review of papers covers all available DEA used approaches and the outcome and progress beyond state of the art, and future work proposed. In particular, we elaborate on the application of DEA in green banking and finance. The paper concludes with the rising importance of DEA applications in banking and finance towards a greater sustainability and green banking sector.

I. INTRODUCTION

Data Envelopment Analysis (DEA) has emerged as a pivotal tool in assessing the efficiency of banking institutions across various contexts. This non-parametric method allows for the evaluation of multiple decision-making units (DMUs) by comparing their input-output ratios without requiring any predefined functional form. The application of DEA in the banking sector has been extensively documented, revealing insights into the efficiency levels, the relative comparative performance, and the impact of various factors on a bank productivity.

One significant study by Jreisat and Al-Mohamad [2] investigates the efficiency of the Bahraini banking industry using DEA. It highlights the DEA effectiveness in benchmarking and its real-world applications in the banking sector. Similarly, Rout et al. [3] focus on the financial efficiency of District Central Cooperative Banks in India, demonstrating that public sector banks outperform their private and foreign counterparts, and suggesting policy interventions to enhance competitiveness. This study aligns with the findings of Kumar and Charles [4] who provide a comprehensive survey of bank efficiency studies, emphasizing the importance of benchmarking in the post-reform period in India.

The comparative analysis between Islamic and conventional banking systems reveals critical insights into efficiency disparities. Fakhrunnas et al. [5] found that conventional banks exhibit higher efficiency levels due to superior management and technological systems compared to their Islamic counterparts. This observation is further supported by studies that explore the broader implications of market concentration and economic growth, as seen in Ferreira's work [6] on the European Union banking sector, which discusses the relationship between bank efficiency and market structure. Moreover, the impact of ownership structures on bank performance has been examined through innovative DEA models. Skully et al. [7] utilized a two-stage dynamic DEA approach to analyze Indian banks before and after the Global Financial Crisis, providing evidence of how ownership influences efficiency. This is complemented by Das and Ghosh's analysis [8] of financial deregulation in India, which employs DEA to distinguish between the technical efficiency variations and the random errors.

The application of DEA extends beyond national contexts, with studies like that of Ghosh et al. [9] focusing on the technical efficiency of Indian banking companies, thereby filling a gap in the literature regarding recent performance metrics. Similarly, Kao and Liu's work [10] on Taiwanese commercial banks employs stochastic DEA to measure efficiency, showcasing the versatility of the method across different banking environments.

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Kumari's survey [1] on recent applications of DEA in the banking sector underscores the method's growing popularity and effectiveness in measuring efficiency. This is echoed in the DEA work of Memic and Škaljić-Memić [11], who analyze the performance of banks in Bosnia and Herzegovina, emphasizing its role as an alternative to traditional financial ratio analysis.

II. DEA BASIC MODEL AND ITS EVOLUTION

DEA is a well-established linear programming (LP) technique for measuring the relative performance of homogeneous Decision-Making Units (DMUs) with multiple inputs and outputs. It was first proposed by Charnes et al. [12] and it has since been widely applied in various fields such as schools, universities, orchestras, museums, hospitals, and public agencies to evaluate the performance of different organizations [13] [14] [13][15] [16] [17].

The main objective of DEA is to assess the relative efficiencies of a set of DMUs based on multiple inputs and outputs. It extends the production function theory and the application technology of microeconomics, and overcomes the subjectivity and limitations of other evaluation methods. DEA can handle both controllable (discretionary) and uncontrollable (non-discretionary) variables, producing a single relative-to-best productivity index that relates all units under comparison [18].

The basic DEA model, known as the Charnes, Cooper, and Rhodes [12], CCR model, is formulated as a fractional programming problem with the objective of maximizing the ratio of virtual output to virtual input [19]The efficiency score of a DMU is calculated as the maximum ratio of the weighted sum of outputs to the weighted sum of inputs, subject to the constraint that the efficiency scores of all DMUs must be less than or equal to 1 [16] [19].

DEA has several advantages, including the ability to accommodate a range of expert opinions on the importance of specific factors, rather than using the median or mean value [20]. It can be used to provide high-risk and low-risk assessments and provides benchmark units from which other units can be evaluated [20].

However, traditional DEA models do not deal with imprecise data and assume that all input and output data are exactly known [21]. To address this, various extensions and modifications of the basic DEA model have been proposed, such as the use of interval data [22], fuzzy data [23], and robust optimization techniques [24].

III. DEA APPLICATIONS IN BANKING AND FINANCIAL SERVICES

One of the primary applications of DEA in banking is the evaluation of operational efficiency. For instance, Rout et al. [3] conducted a study on the productive efficiency of district central cooperative banks in India, revealing that public sector banks outperformed their private and foreign counterparts. This study underscores the utility of DEA in identifying performance disparities among different banking sectors, suggesting that policy interventions could enhance competitive standing by addressing inefficiencies such as non-performing assets [3]. Similarly, Kamarudin et al. [25] assessed the revenue efficiency of Malaysian banks, finding that domestic Islamic banks lagged behind foreign counterparts, further illustrating DEA's role in benchmarking performance across institutions.

Moreover, DEA has been effectively utilized in risk management within financial institutions. Jomthanachai et al. [26] integrated DEA with machine learning techniques to enhance risk assessment processes, demonstrating that DEA can provide a robust framework for evaluating the efficiency of DMUs in managing risks, which is crucial for maintaining financial stability. This dual approach not only improves the understanding of risk levels but also aids in the strategic allocation of resources to mitigate potential failures.

In addition to operational efficiency and risk management, DEA has been instrumental in assessing the financial and social performance of microfinance institutions (MFIs). Studies such as those by Bibi et al. [27] and Efendic and Hadziahmetovic [28] have highlighted the dual efficiency of MFIs, emphasizing the importance of both financial sustainability and social outreach. These studies employed DEA to analyze the efficiency of MFIs in South Asia and Bosnia and Herzegovina, respectively, revealing that while many MFIs excel in financial efficiency, they often struggle

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with social efficiency, indicating a need for balanced performance metrics. This dual focus is critical in the context of microfinance, where the mission often encompasses both profit generation and social impact.

Furthermore, the application of DEA extends to the evaluation of bank performance in the context of financial crises. Bapat [29] 's research on Indian banks during the global financial crisis utilized DEA to assess the impact of the crisis on public and private sector banks, revealing significant insights into how different banking models withstand economic shocks [29]. This DEA application not only aids in understanding historical performance but it also informs future strategies for resilience in the banking sector.

A. Approach and Methodology

Data Envelopment Analysis (DEA) is a widely utilized methodology for assessing the relative efficiency of decision-making units (DMUs), such as banks and financial institutions. It employs linear programming to evaluate how well these entities convert multiple inputs into multiple outputs, thereby generating efficiency scores that facilitate comparisons among them. The foundational principles of DEA were established in the seminal works of Charnes, Cooper, and Rhodes [12], which have since led to extensive applications across various sectors, particularly in banking and financial services [30] [31] [1].

In the context of banking, DEA has been instrumental in measuring technical efficiency and identifying best practices. For instance, Varma and Nijjer [32] utilized DEA to assess the efficiency of banks in India, revealing significant insights into the relationship between FinTech innovations and bank performance. Similarly, Ullah et al. [33] highlighted the application of DEA in evaluating the efficiency of banks in Pakistan, noting that the sector's performance has lagged in adapting to new financial environments. This adaptability is crucial, especially in light of evolving regulatory frameworks and risk management practices that have emerged in recent years.

The DEA methodology involves selecting appropriate sets of input and output variables that reflect the operational realities of banks. Inputs typically include resources such as labor, capital, and operational costs, while outputs can encompass various performance metrics like loans issued, deposits, and profit margins. For example, Rout et al. [3] applied DEA to measure the financial efficiency of district central cooperative banks in India, demonstrating that public sector banks outperformed their private and foreign counterparts. This finding underscores the importance of contextualizing DEA applications to specific banking environments and regulatory frameworks.

Moreover, the flexibility of DEA allows for the incorporation of various factors influencing bank efficiency. For instance, Yang's study [34] on non-performing loans (NPLs) illustrated how DEA can accommodate multiple inputs and outputs, thus providing a nuanced view of bank efficiency in the face of credit risk challenges. This adaptability is further exemplified by the work of Kondova and Bandyopadhyay [35] who explored the impact of non-bank lending on the efficiency of European banks, employing DEA to analyze post-crisis performance.

In addition to traditional DEA applications, recent advancements have introduced more sophisticated models, such as network DEA and fuzzy DEA, which enhance the robustness of efficiency assessments. For example, Dia et al. [36] developed a three-stage network DEA model to evaluate the performance of Canadian banks, integrating bootstrapping techniques to address data variability and improve reliability. This evolution in DEA methodologies reflects a growing recognition of the complexity inherent in banking operations and the need for more refined analytical tools.

B. Outcomes and Findings

Data Envelopment Analysis (DEA) has emerged as a pivotal tool in assessing the efficiency of banking and financial services, demonstrating significant advancements beyond traditional methodologies. This non-parametric approach evaluates the relative efficiency of decision-making units (DMUs), such as banks, by comparing multiple inputs and outputs, thus providing a comprehensive view of operational performance in a complex environment.

One of the notable applications of DEA in banking is its integration with corporate social responsibility (CSR) metrics. Research indicates that CSR positively influences bank efficiency, as evidenced in studies conducted in Indonesia and China, where DEA was employed to measure the impact of sustainable banking practices on financial performance [37] [38]. This highlights a growing trend where banks are not only evaluated on financial metrics but also on their social and environmental contributions, aligning with global sustainability goals.

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In the context of Islamic banking, DEA has been utilized to explore the efficiency of Sharia-compliant financial institutions. Studies have suggested that the principles of value-based banking can be integrated with Islamic finance to enhance operational efficiency and social impact [39]. Furthermore, comparative analyses using DEA have shown that conventional banks often outperform their Islamic counterparts in terms of efficiency, primarily due to differences in management practices and technological adoption [5]. This underscores the necessity for Islamic banks to adopt innovative strategies to improve their competitive edge.

The application of DEA is not limited to efficiency measurement; it also extends to understanding the effects of macroeconomic factors on banking performance. For instance, research has demonstrated that external economic conditions significantly influence the efficiency levels of banks, with DEA providing insights into how banks can optimize their operations in varying economic climates [5] [40]. This adaptability is crucial, especially in the wake of disruptions such as the COVID-19 pandemic, which has necessitated a re-evaluation of operational strategies in the banking sector [40].

Moreover, the evolution of DEA methodologies, such as the two-stage network DEA model, has allowed for a more nuanced analysis of bank performance. This model decomposes the efficiency of banking processes into sub-processes, facilitating a detailed understanding of where inefficiencies may arise within the operational framework [41]. Such advancements in DEA applications enable policymakers and bank managers to implement targeted interventions aimed at enhancing overall efficiency.

C. Proposed Future Work

Data Envelopment Analysis (DEA) has emerged as a pivotal tool for evaluating the efficiency of banking and financial services. Its application in this sector is particularly relevant given the increasing complexity of financial operations and the need for robust performance metrics. DEA allows for the assessment of relative efficiency among various decision-making units (DMUs), such as banks, by comparing multiple inputs and outputs without requiring a predefined functional form of the production process. This non-parametric approach is beneficial in capturing the multifaceted nature of banking operations, which often involve various financial products and services.

One significant area where DEA can be applied is in the optimization of credit risk management. For instance, Lai et al. [42] demonstrated that DEA can effectively evaluate the efficiency of financial firms in Malaysia, highlighting how resources can be utilized to maximize outputs while minimizing inputs. This approach not only aids in identifying inefficient practices but also provides a framework for benchmarking against industry standards. Similarly, the work of Ghaeli [43] emphasizes the importance of DEA in measuring the relative efficiency of banks, showcasing its utility in comparative analyses between different financial institutions in USA and Canada.

Moreover, the application of DEA extends to the assessment of operational performance within banks. Preeti and Roy [44] have noted that traditional performance measures often fall short in capturing the dynamic nature of banking operations, thus advocating for the adoption of DEA as a more effective alternative. This sentiment is echoed by Kumari [1], who reviewed recent applications of DEA in the banking sector, underscoring its growing relevance in performance evaluation. The ability of DEA to incorporate multiple performance indicators makes it a versatile tool for financial institutions seeking to enhance their operational efficiency.

In the context of the global financial landscape, DEA can also play a crucial role in understanding the impact of external economic factors on bank performance. For instance, Dia et al. [36] utilized a three-stage DEA model to evaluate the performance of Canadian banks during the financial crisis, identifying best practices that could serve as benchmarks for improving economic sustainability. This highlights the adaptability of DEA in various economic contexts and its potential to inform strategic decision-making in banking.

Furthermore, the integration of DEA with advanced methodologies, such as bootstrapping, has been proposed to enhance the accuracy of efficiency estimates. This is particularly relevant in the financial services sector, where the precision of efficiency scores can significantly influence managerial decisions and policy formulations, Kaffash and Marra [45]. The work of Assaf and Matawie [46] illustrates how bootstrapping can improve the reliability of DEA results, thereby providing more robust insights into operational efficiencies.

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IV. DEA APPLICATIONS IN GREEN BANKING

Data Envelopment Analysis (DEA) has emerged as a pivotal tool in evaluating the efficiency of banks, particularly in the context of green banking initiatives. The application of DEA in this sector is crucial for assessing how well banks utilize their resources to promote sustainability while maintaining operational efficiency. Various studies have highlighted the effectiveness of DEA in measuring bank performance, particularly in relation to sustainable banking practices.

Kosasih et al. [37] conducted a comprehensive study examining the impact of sustainable banking disclosures on bank efficiency across 41 countries. Their findings suggest that banks that actively engage in sustainability practices tend to demonstrate higher efficiency levels, as measured by DEA. This aligns with the notion that transparency in sustainability efforts can enhance operational performance, thereby supporting the broader objectives of green banking.

Similarly, Shah et al. [47] explored the efficiency and productivity of sustainable banks using DEA and the Malmquist Productivity Index. Their research indicates that sustainable banks not only achieve efficiency but also contribute positively to environmental goals. This reinforces the idea that integrating sustainability into banking operations can yield beneficial outcomes both for the banks themselves and for the environment.

Moreover, Belasri et al. [38] emphasized the importance of corporate social responsibility (CSR) in enhancing bank efficiency. Their analysis indicates that banks that prioritize CSR initiatives, which often include green banking practices, tend to perform better in terms of efficiency metrics derived from DEA. This suggests a strong correlation between CSR activities and operational efficiency, highlighting the potential for banks to leverage sustainability as a competitive advantage.

In the context of Islamic banking, Kaban & Setyawati [48] utilized DEA to analyze the efficiency of sharia banking in the era of Industry 4.0. Their findings indicate that sharia banks, which often incorporate ethical and sustainable practices, can achieve significant efficiency gains through the application of DEA. This underscores the versatility of DEA in assessing various banking models, including those focused on sustainability.

Furthermore, the application of DEA is not limited to traditional banking models. For instance, Wu et al. [49] applied DEA to assess the efficiency of commercial banks in Ghana, emphasizing the role of efficiency measures in achieving sustainable development. Their study highlights how DEA can be instrumental in identifying inefficiencies that hinder the adoption of green banking practices, thereby providing a pathway for improvement.

A. Approach and Methodology

Data Envelopment Analysis (DEA) has emerged as a prominent methodology for evaluating the efficiency of banks, particularly in the context of green banking practices. This approach allows for the assessment of multiple inputs and outputs, making it particularly suitable for the complex nature of banking operations, which often involve both financial and non-financial metrics. The application of DEA in green banking is significant as it helps to quantify the efficiency of banks in implementing sustainable practices while maintaining financial performance.

One of the key strengths of DEA is its ability to provide a non-parametric measure of efficiency, which is crucial for comparing banks that may differ significantly in size and operational focus. For instance, Kosasih et al. [37] utilized DEA to analyze the efficiency of banks in Indonesia, demonstrating how sustainable banking disclosures can impact overall bank efficiency. Similarly, Belasri et al. [38] highlighted that DEA is one of the most effective techniques for assessing bank performance, particularly in the context of corporate social responsibility, which is closely aligned with green banking initiatives.

Moreover, the DEA methodology has been applied in various studies to evaluate the operational efficiency of banks in different regions and contexts. For example, Pan et al. [50] employed the DEA-Malmquist index to assess the green credit operations of commercial banks, illustrating how the methodology can adapt to evaluate specific aspects of banking performance related to environmental sustainability. This adaptability is further supported by the findings of Ullah et al. [33] who noted that DEA effectively measures the efficiency of banks in transforming multiple inputs into outputs, is a critical aspect when considering the integration of green practices.

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The application of DEA extends beyond mere efficiency measurement; it also facilitates the identification of best practices within the banking sector. As noted by Staub et al. [51], DEA can compute efficiency scores that help banks benchmark their performance against peers. This benchmarking is essential for banks aiming to enhance their green banking initiatives, as it provides insights into areas for improvement and potential strategies for adopting more sustainable practices.

Furthermore, the literature indicates that DEA can be effectively combined with other analytical methods to enhance the robustness of findings. For instance, the study by Jiang and He [52] emphasize the importance of using a multi-input and multi-output framework to evaluate bank performance comprehensively. This approach aligns well with the objectives of green banking, where both financial and environmental outcomes are critical.

B. Outcomes and Findings

The application of Data Envelopment Analysis (DEA) in green banking has progressed significantly, moving beyond traditional efficiency measurements to incorporate sustainability factors, thereby aligning with the growing emphasis on corporate social responsibility (CSR) in the banking sector.

Recent studies have highlighted the effectiveness of DEA in evaluating bank efficiency while considering sustainability disclosures. For instance, Kosasih et al. [37] demonstrated that sustainable banking disclosures positively influence bank efficiency, suggesting that banks that prioritize sustainability can achieve better operational performance through enhanced efficiency metrics derived from DEA. This aligns with the findings of Belasri et al. [38], who noted that traditional ratio analysis falls short in capturing the multifaceted nature of bank operations, advocating for DEA as a superior method for assessing performance in complex banking environments. By integrating sustainability into efficiency assessments, DEA not only measures financial performance but also evaluates the impact of environmental practices on bank operations.

Moreover, the application of DEA has evolved to include comparisons between different banking models, such as conventional and Islamic banks. Studies have shown that conventional banks often exhibit higher efficiency levels due to better management practices and technological advancements [5]. This comparative analysis is crucial for understanding how different banking frameworks can adopt green practices effectively. For example, Kaban and Setyawati's research [48] on Sharia banking in the context of Industry Revolution 4.0 highlighted the need for these banks to enhance their efficiency through innovative practices, which could include green banking initiatives.

The integration of fintech into banking operations has also been analyzed through the lens of DEA. Research by Maryunita and Nugroho [53] indicated that fintech adoption significantly impacts the efficiency of conventional banks in Indonesia, suggesting that technological advancements can facilitate the implementation of green banking practices. This trend is supported by findings from Kumari [1], who reviewed various applications of DEA in the banking sector, emphasizing its role in measuring efficiency in the context of emerging technologies. The intersection of fintech and green banking presents a unique opportunity for banks to enhance their operational efficiency while adhering to sustainability principles.

Furthermore, the exploration of macroeconomic factors influencing banking efficiency has been enriched by DEA methodologies. Studies have shown that factors such as non-performing loans (NPLs) negatively affect bank efficiency, underscoring the importance of sound financial management in achieving sustainable banking outcomes, Riani and Maulani [54]. The ability of DEA to incorporate various input and output variables makes it an invaluable tool for identifying the determinants of efficiency in the banking sector, particularly in the context of green banking initiatives.

C. Proposed Future Work

The application of Data Envelopment Analysis (DEA) in the context of green banking presents a promising avenue for enhancing the efficiency and sustainability of banking operations. DEA, as a non-parametric method, is particularly adept at evaluating the relative efficiency of decision-making units (DMUs) such as banks by comparing multiple inputs and outputs. This capability is crucial in green banking, where financial institutions are increasingly tasked with integrating environmental considerations into their operational frameworks.

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One of the key determinants of banking efficiency, as highlighted in various studies, is the effective management of resources. For instance, Ikapel [55] emphasizes that factors such as bank size, capital adequacy, and liquidity risk significantly influence the efficiency of banks. This insight is particularly relevant for green banking, where the efficient allocation of resources towards sustainable projects can enhance overall performance. Furthermore, the findings of Kaban & Setyawati [48] support the notion that DEA serves as a robust tool for measuring efficiency, particularly in the context of evolving banking landscapes influenced by technological advancements and regulatory changes.

Moreover, the two-stage DEA approach, as discussed by Nugrohowati [53], can be instrumental in green banking applications. This methodology not only assesses the efficiency levels of banks but also identifies the determinants of that efficiency, which is essential for implementing effective green banking strategies. By understanding the factors that contribute to efficiency, banks can better align their operations with sustainability goals, thereby improving their environmental impact while maintaining financial performance.

The integration of DEA in assessing the efficiency of green banking initiatives can also provide valuable insights into the comparative performance of different banking models. For instance, studies have shown that Islamic banks often exhibit different efficiency levels compared to conventional banks, as noted by Çelik and Öncü [56]. This comparative analysis can be extended to evaluate how various banking models adopt green practices and their resultant efficiencies, thereby guiding policy decisions and strategic planning in the banking sector.

Furthermore, the application of DEA can facilitate the identification of inefficiencies within banks, as highlighted by Marjanović et al. [57]. By pinpointing areas where banks may be underperforming, particularly in their green initiatives, management can implement targeted strategies to enhance efficiency. This is crucial in a competitive banking environment where sustainability is becoming a key differentiator.

V. CONCLUSION

Data Envelopment Analysis (DEA) is a robust framework for assessing bank efficiency, providing valuable insights into the operational performance of financial institutions across various regions and contexts. The method's flexibility in incorporating multiple inputs and outputs without strict assumptions makes it particularly suitable for the complex nature of banking operations.

The basic DEA model is a powerful tool for evaluating the relative efficiency of DMUs with multiple inputs and outputs, and has been widely applied in various fields to measure and benchmark the performance of different organizations.

DEA serves as a versatile and powerful tool in the banking and financial services sector, providing comprehensive insights into efficiency, risk management, and performance assessment. Its ability to evaluate multiple dimensions of performance makes it invaluable for policymakers and financial managers aiming to enhance operational effectiveness and ensure sustainable growth.

DEA serves as a powerful tool for measuring and benchmarking the efficiency of banks and financial institutions. Its application across diverse contexts, from emerging markets to developed economies, demonstrate its versatility and relevance in contemporary financial analysis. As the banking landscape continues to evolve with technological advancements and regulatory changes, DEA will remain a critical methodology for understanding and enhancing operational efficiency.

DEA serves as a robust framework for evaluating the efficiency of banking and financial services. Its ability to integrate multiple performance metrics and adapt to various financial contexts makes it an invaluable tool for researchers and practitioners alike. The extensive literature on DEA applications in banking underscores its significance in enhancing operational efficiency, informing policy decisions, and predicting financial outcomes.

The future application of Data Envelopment Analysis in banking and financial services is poised to expand significantly. Its ability to provide nuanced insights into efficiency, coupled with its adaptability to various economic conditions and integration with advanced statistical techniques, positions DEA as an essential tool for financial institutions aiming to optimize performance and manage risks effectively.

The application of DEA in banking and financial services has progressed significantly, moving beyond traditional efficiency assessments to encompass a broader range of factors, including CSR, macroeconomic influences, and

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innovative modeling techniques. This evolution reflects a deeper understanding of the complexities within the banking sector and the need for multifaceted approaches to performance evaluation.

Moreover, the future application of Data Envelopment Analysis in green banking holds significant potential for improving the efficiency of banking operations while promoting sustainable practices. By leveraging the insights gained from DEA, banks can enhance their resource allocation, benchmark against peers, and ultimately contribute to a more sustainable financial ecosystem.

The application of Data Envelopment Analysis in green banking is well-supported by empirical evidence across various studies. DEA serves as a robust framework for evaluating the efficiency of banks in their pursuit of sustainability, demonstrating that banks can achieve operational excellence while contributing to environmental goals. The integration of sustainability into banking practices is not only beneficial for the environment but also enhances the overall efficiency and competitiveness of financial institutions.

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