Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-023-02581-2 OPEN

Unveiling the landscape of Fintech in ASEAN: assessing development, regulations, and economic implications by decision-making approach

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Fintech has gained immense importance as a catalyst for economic growth, trade enhancement, and global prosperity. This study aims to comprehensively assess the influence and potential of Fintech in the Association of Southeast Asian Nations (ASEAN) countries. The research objective is to evaluate the levels of development in financial activities, technology infrastructure, and Fintech-enabling regulations across the region. A robust decision-making framework combining numerical and linguistic assessments is applied, utilizing the Distance-based CRiteria Importance Through Inter-criteria Correlation (DCRITIC) method and the Fuzzy extension of Evaluation based on Distance from Average Solution (F-EDAS approach). The findings reveal varying levels of development among ASEAN countries about Fintech. Governments and policymakers are urged to prioritize the creation of a supportive environment for Fintech innovation to spur economic growth, attract investments, and foster digital transformation. The study is limited because the weights of the key regulations have not been investigated.

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Introduction

The Association of Southeast Asian Nations (ASEAN), comprising Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam, plays a significant role in global economic dynamics. These nations contribute notably to economic growth, trade, investment attractiveness, and global production networks, enhancing regional and global economic prosperity (Dang and Nguyen, 2021; UNTCAD, 2022). The ASEAN region contributes over 10% to the GDP of the East Asia and Pacific region (World Bank Open Data, 2022). Despite these advancements, it is crucial to acknowledge the diverse economic performance, development strategies, and policy priorities across ASEAN countries (Georgieva, 2022; Hong et al. 2022).

Fintech's emergence as a transformative force in the financial sector has been widely acknowledged. It has revolutionized financial services by utilizing technology to enhance financial inclusion, streamline processes, and broaden access to capital (Buntinx, 2023; Firmansyah et al. 2023; Primeaux et al. 2017; Sahay et al. 2020). Fintech's impact spans various domains, including digital payments, investment, lending, and regulatory compliance, fundamentally altering financial management practices (Primeaux et al. 2017).

In the context of ASEAN, Fintech significantly contributes to economic growth and financial inclusion. It challenges traditional financial institutions through innovative technologies such as AI, blockchain, and data analytics (UOB, 2023). The sector's digital payments and remittances transformation has streamlined processes, reducing costs and enhancing efficiency (Sinay et al. 2021). Fintech's support for SMEs and its role in promoting financial literacy through various platforms is also noteworthy (Creehan et al. 2019; Jain et al. 2023). The collaboration between Fintech companies and regulators in ASEAN is critical to ensuring a regulated and innovative financial ecosystem (Advancing Digital Financial Inclusion in ASEAN: Policy and Regulatory Enablers, 2020; Fintech and Financial Literacy Roundtable, 2021; Inclusion, 2021). However, the existing literature reveals a significant research gap in understanding the disparities in Fintech development across ASEAN countries, as shown in Fig. 1 (Cornelli et al. 2020). This gap in understanding the uneven development and adoption of Fintech solutions across diverse economic and regulatory landscapes in ASEAN forms the core of this study's research focus.

This study aims to address this gap by providing a detailed analysis of Fintech's influence and potential across the ASEAN region. It evaluates the impact of Fintech based on three key aspects: the influence of financial activities on economies, the state of technology infrastructure, and the environment of Fintech-enabling regulations. The study employs an integrated multiple-criteria decision-making approach, combining Distance-based CRiteria Importance Through Inter-criteria Correlation (DCRITIC) and Evaluation based on Distance from Average Solution (EDAS) for assessing financial activities and technological infrastructure. The Fuzzy EDAS (F-EDAS) method is used for evaluating regulatory frameworks.

The theoretical contribution of this study lies in introducing a unique decision-making framework capable of simultaneously analyzing numerical and linguistic data. The DCRITIC method is utilized for weighting criteria and prioritizing alternatives based on numerical data correlation, while the F-EDAS method is used for quantifying and analyzing linguistic evaluations. The results integrate these analytical processes.

The research consists of five sections. "Introduction" introduces the topic, outlines its objectives, and highlights its significance. "Literature review" reviews existing literature and identifies gaps. "Methodology" explains the methodology. "Numerical results" presents numerical results and analysis. "Conclusion" offers a concise conclusion with findings, implications, and future research recommendations.

Literature review

Fintech, the intersection of finance and technology, has garnered significant attention in recent years, leading to a surge of research exploring its various dimensions. This literature review aims to provide an overview of key research themes and findings in fintech. By examining the current state of knowledge, this review aims to shed light on the advancements, challenges, and future directions in fintech-related research.

Understanding the factors influencing fintech adoption and user behavior has been a primary focus of research. Scholars have investigated the impact of trust, perceived usefulness, ease of use, and social influence on fintech adoption among consumers (Firmansyah et al. 2023). Additionally, studies have explored demographic factors, such as age, gender, and income, about fintech usage patterns (Aggarwal et al. 2023). Financial inclusion, particularly in underserved populations, has been a prominent theme in fintech research. Scholars have examined how fintech innovations, such as mobile banking and digital wallets, can enhance access to financial services for the unbanked and underbanked (Team). Research has highlighted the potential of fintech to improve financial literacy, promote savings behavior, and facilitate small business growth in developing countries (Appaya, 2021; Tok and Heng, 2022). The rise of blockchain technology and cryptocurrencies has spurred extensive research. Studies have explored the potential of blockchain to enhance transparency, security, and efficiency in financial processes (Urquhart and Lucey, 2022). Research has also focused on the dynamics of cryptocurrency markets, investor behavior, and the regulatory challenges associated with digital currencies (Yuan and Wang, 2018). The impact of fintech on traditional financial institutions has been the subject of significant research. Scholars have investigated how fintech startups and digital platforms

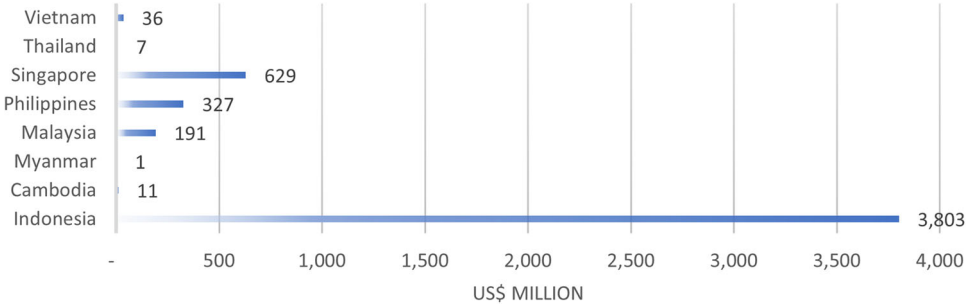

Fig. 1 The ASEAN's Fintech credit in 2019. Distribution of fintech credit across ASEAN countries in 2019.

disrupt and reshape the banking and insurance sectors (Buntinx, 2023). Research has examined the strategies employed by incumbent institutions to collaborate with or compete against fintech firms (Haddad and Hornuf, 2023; Shoushany, 2023). The regulatory implications of fintech have garnered considerable attention. Studies have examined the regulatory challenges and frameworks surrounding fintech innovations, including issues related to consumer protection, data privacy, and cybersecurity (Hazdun, 2022). Research has explored the role of regulatory sandboxes and innovation hubs in fostering fintech development (Primeaux et al. 2017).

The literature on fintech encompasses a broad range of topics, including adoption behavior, financial inclusion, blockchain, cryptocurrencies, interactions with traditional financial institutions, and regulatory challenges. This literature review has highlighted key research findings within these areas. Future research directions may involve exploring emerging technologies, such as artificial intelligence and machine learning, within fintech, as well as investigating the societal impact of fintech and addressing evolving regulatory frameworks. The field of fintech research continues to evolve rapidly, offering promising avenues for further exploration and inquiry.

The recent literature on Fintech, corporate environmental performance, and sustainability in business highlights the multifaceted impact of technological advancements and leadership on various sectors. Huawei Tian et al. (2023) focus on the intersection of Fintech innovation and green transformational leadership (GTL) in enhancing corporate environmental performance (ENP) within Bangladeshi manufacturing SMEs (Tian et al. 2023). Employing ecological modernization theory (EMT) and ability-motivation-opportunity (AMO) frameworks, the study reveals that Fintech adoption and GTL positively influence green innovation and ENP. The use of the advanced structural equation modeling-artificial neural network (SEM–ANN) technique underscores the robust methodological approach to analyzing these relationships. Sahar Afshan et al. (2024) delve into the complex relationship between Fintech, digital currencies, exchange rates, and economic stability amid oil price volatility (Afshan et al. 2024). The research employs Morlet Wavelet and time-frequency decomposition techniques, showcasing a methodological advancement to explore these interconnections. The study identifies positive coherence between Fintech and digital currency with exchange rates, indicating Fintech's stabilizing potential against financial risks. Abu Bakkar Siddik et al. (2023) examine the role of Fintech Adoption (FA) and Financial Literacy (FL) on corporate sustainability performance (CSP), drawing from EMT and resource-based view (RBV) (Siddik et al. 2023). The study identifies Access to Finance (AF) as a critical mediator in enhancing CSP, providing empirical data from the Bangladeshi apparel industry. This work extends the theoretical frameworks of EMT and RBV by integrating FA, FL, and AF as pivotal resources for sustainability. Alexey Mikhaylov (2023) addresses the risks associated with the crypto space, analyzing various academic papers to offer policy recommendations (Mikhaylov, 2023). The review stresses the need for regulatory frameworks for digital assets, highlighting the responsibilities of national and international authorities, as well as market operators, to manage the emerging risks in the cryptocurrency market effectively. Pavla Srbová et al. (2023) investigate the influence of corporate social responsibility (CSR) on the economic performance of Czech family MSMEs (Srbová et al. 2023). The research corroborates the positive impact of CSR principles on profitability and indebtedness, emphasizing the role of family businesses in promoting work-life balance and good employee relations for long-term sustainability. Theodore Metaxas et al. (2023) discuss the Madrid Nuevo Norte Project (MNNP) from a sustainability perspective, using qualitative approaches and semi-structured interviews with experts (Metaxas et al. 2023). The study underlines the challenges and opportunities in urban development, stressing the importance of sustainability, social justice, and prosperity in mega-projects. While existing research provides valuable insights into the interplay between Fintech, sustainability, and CSR, there remains a gap in the application of these findings to the ASEAN context. Studies have yet to fully explore how Fintech can bolster CSR and sustainability within ASEAN's unique economic and regulatory environments. Our study seeks to address this gap, offering a targeted analysis of Fintech's role in advancing sustainable development and CSR across ASEAN, thus enriching the global discourse with region-specific insights.

Multiple Criteria Decision-Making (MCDM) is a field of study that deals with decision problems involving multiple and conflicting criteria. Over the years, numerous MCDM methods have been developed to assist decision-makers in making informed and rational choices. This literature review aims to provide an overview of the development of MCDM methods, highlighting key contributions, approaches, and advancements in the field. The development of MCDM methods can be traced back to the mid-20th century. One of the earliest and most influential methods is the Analytic Hierarchy Process (AHP) proposed by Thomas Saaty (Saaty, 2008). AHP decomposes complex decision problems into hierarchical structures and employs pairwise comparisons to determine criteria weights and alternatives' rankings (Liu et al. 2020). Another notable method is the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) introduced by Hwang and Yoon (Hwang et al. 1981). TOPSIS determines the best alternative based on the shortest distance to the ideal solution and the farthest distance to the negative ideal solution. The Multi-Attribute Utility Theory (MAUT) is a prominent approach in MCDM that quantifies decision-maker preferences using utility functions. The development of MAUT can be attributed to the works of Keeney and Raiffa (1976) (Keeney and Raiffa, 1976) and von Winterfeldt and Edwards (1986) (von Winterfeldt and Edwards, 1986). MAUT combines various criteria into a utility function and allows decision-makers to express their preferences by assigning weights to the criteria and assessing the utility of alternatives. As decision problems became more complex, evolutionary and heuristic approaches emerged in MCDM. The Multi-Criteria Decision Analysis (MCDA) framework provides a systematic and structured approach to decision-making. MCDA integrates various MCDM methods, techniques, and tools into a comprehensive decision-making process. It involves problem structuring, criteria identification, data collection, model development, sensitivity analysis, and decision support. The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and ELECTRE (Elimination and Choice Expressing Reality) methods are widely used within the MCDA framework (Behzadian et al. 2010; Jun et al. 2014; J. M. Sánchez-Lozano et al. 2016; Juan M. Sánchez-Lozano et al. 2014). To address the limitations of individual methods and leverage their strengths, researchers have developed hybrid and integrated MCDM approaches (Tzeng and Shen, 2017). Hybrid methods combine multiple techniques to enhance decision-making accuracy and robustness (Le and Nhieu, 2022a; Wang et al. 2021). The development of fuzzy theory in MCDM has provided valuable tools and techniques for handling imprecise and uncertain information in decision-making processes (Liu et al. 2020). Fuzzy sets, linguistic variables, fuzzy aggregation operators, and fuzzy decision-making approaches have enhanced the flexibility, robustness, and intuitiveness of MCDM methods(Mardani et al. 2015). Fuzzy optimization and fuzzy programming have extended traditional optimization techniques to handle fuzzy or uncertain data(Wang et al. 2021). The application

of fuzzy theory in MCDM continues to evolve, offering promising avenues for further research and practical applications in various domains.

The CRITIC method, proposed by Diakoulaki et al. (1995), is a widely used MCDM method that considers the inter-criteria correlation to determine the importance weights of criteria (Diakoulaki et al. 1995). It addresses the limitations of the AHP by incorporating the correlations among criteria. The CRITIC method utilizes pairwise comparisons to derive the weights of criteria and considers the inter-criteria correlation matrix to capture the dependencies between criteria. This method provides a more accurate assessment of the criteria's importance and improves the decision-making process by accounting for the relationships among criteria. The EDAS method, introduced by Keshavarz et al. (2015), is a distance-based MCDM method that evaluates alternatives based on their distance from the average solution (Keshavarz Ghorabaee et al. 2015). It offers a flexible approach to decision-making by considering the distance of alternatives from both positive and negative ideal solutions. The EDAS method employs the Euclidean distance and the Hamming distance to measure the proximity of alternatives to the ideal solutions. By calculating the distances, the EDAS method ranks the alternatives and provides a comprehensive evaluation of their performance.

The development of MCDM methods has significantly contributed to improving decision-making processes in various domains. The CRITIC method has enhanced the accuracy of determining the importance of criteria by incorporating inter-criteria correlation. It offers a more comprehensive approach to evaluating alternatives by considering their distances from both positive and negative ideal solutions. The CRITIC method and the EDAS method have provided decision-makers with valuable tools for assessing the importance of criteria and ranking alternatives, enabling them to make informed and rational decisions in complex decision problems.

The literature on fintech covers a wide range of topics, including adoption behavior, financial inclusion, blockchain, cryptocurrencies, and regulatory challenges. Meanwhile, MCDM methods have revolutionized decision-making processes across various domains by incorporating inter-criteria correlation and considering distances from ideal solutions. By combining these two fields, we can unlock new insights and methodologies for informed decision-making in the fintech landscape. To date, research in fintech has uncovered key findings and highlighted emerging trends. However, there are still unexplored avenues that warrant attention. Future research directions could focus on harnessing emerging technologies like artificial intelligence and machine learning to propel fintech innovation. Additionally, investigating the societal impact of fintech and addressing evolving regulatory frameworks are crucial to ensure sustainable and responsible fintech practices. Integrating MCDM methods into fintech research can enhance the accuracy of determining the importance of criteria and provide decision-makers with comprehensive tools for evaluating alternatives. The CRITIC method, with its incorporation of inter-criteria correlation, offers a robust approach to assessing the importance of criteria, while the EDAS method considers distances from both positive and negative ideal solutions to rank alternatives effectively. Leveraging these methods in the fintech context will enable decision-makers to navigate complex decision problems with confidence and make rational choices.

Methodology

Fuzzy sets. The fuzzy sets are used both for criteria weighting and for alternative prioritization processes to support the decision-making procedure under ambiguous conditions. (Bellman and Zadeh, 1970; Zadeh, 1965).

Definition 1. Let $\widetilde{a} \in F(R)$ be a fuzzy number if: $\widetilde{a}_\varepsilon = [x, \mu_{\widetilde{a}_\varepsilon}(x) \geq \delta]$ is a closed interval for any $\delta \in [0,1]$; There exists $x_0 \in R$ such that $\mu_{\widetilde{x}}(x_0) = 1$. Where $\mu_{\widetilde{a}}(x)$, $F(R)$, and R represent the membership function, fuzzy set, and real number set respectively (Guo and Zhao, 2017).

Definition 2. A triangular fuzzy number (TFN) denoted by $\tilde{a} = (s, m, l)$. Where s, m, and l represent the smallest, most likely, and largest possible value of TFN $\tilde{a}$. Thus, the membership function of $\tilde{a}$ can be defined as Eq. (1) (Hwang and Yoon, 1981).

$$\mu_{\tilde{a}}(x) = \begin{cases} \frac{x-s}{m-s}, & s \leq x < m \\ \frac{l-x}{l-m}, & m \leq x \leq l \\ 0, & otherwise \end{cases} \tag{1}$$

Definition 3. Consider two TFNs $\tilde{a}_1 = (s_1, m_1, l_1)$ and $\tilde{a}_2 = (s_2, m_2, l_2)$. The basic operators of can be defined as Eqs.(2)–(6) (Li, 2010):

$$\widetilde{a}_1 + \widetilde{a}_2 = (s_1 + s_2, m_1 + m_2, l_1 + l_2) \tag{2}$$

$$\widetilde{a}_1 \times \widetilde{a}_2 = (s_1 \times s_2, m_1 \times m_2, l_1 \times l_2) \tag{3}$$

$$\widetilde{a}_1 - \widetilde{a}_2 = (s_1 - l_2, m_1 - m_2, l_1 - s_2) \tag{4}$$

$$\widetilde{a}_1 \div \widetilde{a}_2 = (s_1 \div l_2, m_1 \div m_2, l_1 \div s_2) \tag{5}$$

$$\frac{1}{\tilde{a}_j} = \left(\frac{1}{l_j}, \frac{1}{m_j}, \frac{1}{s_j}\right) \tag{6}$$

Definition 4. The TFNs are transformed into a crisp value $(\varphi(\widetilde{x}))$ as a graded mean as Eq. (7) (Yao and Wu, 2000):

$$\varphi(\widetilde{a}) = \frac{s + 2m + l}{4} \tag{7}$$

The proposed assessment framework. As illustrated in Fig. 2, this study proposes an assessment framework that simultaneously evaluates quantitative indicators and qualitative information. First, indicators and information are selected through references. On the one hand, indicators are objectively weighted through statistical parameters such as standard deviation and correlation between indicators. This process is performed according to the procedure of the DCRITIC method. Next, the EDAS method is used to determine the scores of alternatives based on indicators. On the other hand, the qualitative information is quantified using the fuzzy theory. Then, the fuzzy extension of EDAS method is applied to determine the scores of alternatives based on information. Ultimately, those scores are the basis for drawing assessment conclusions.

Distance-based CRITIC (DCRITIC). The CRITIC method, also known as CRiteria Importance through Inter-criteria Correlation, is a decision-making technique used to determine the relative importance of criteria or factors in a multi-criteria analysis (Diakoulaki et al., 1995). It provides a systematic approach to assess the significance of various criteria and their interrelationships in decision-making processes. The CRITIC method relies on the principle that the importance of a criterion can be inferred from its correlation with other criteria. The method starts by constructing a pairwise correlation matrix that captures the relationships between each pair of criteria. The CRITIC method helps in this process by providing a quantitative approach to determine the relative

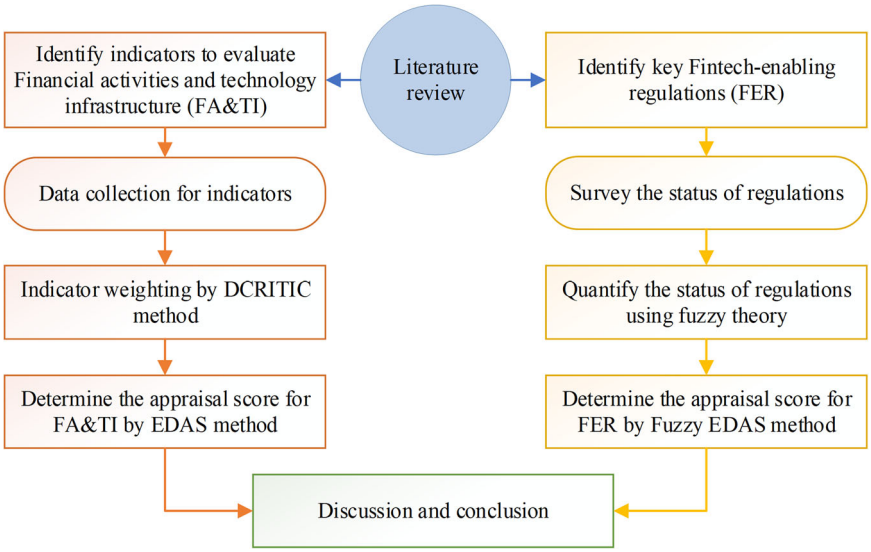

Fig. 2 The proposed assessment framework flowchart. Flowchart of the proposed framework for assessing fintech development status in ASEAN.

importance of these criteria. In 2022, N. Sharkasi and S. Rezakhah present modifications to the CRITIC method in MCDM (Sharkasi and Rezakhah, 2022). An illustrative example of ranking display advertisement performance criteria demonstrates the method's effectiveness. The DCRITIC procedure can be expressed as following steps:

Step 1: Establish the decision matrix consisting of I $(i = 1 \ldots I)$ alternatives and $(j = 1 \ldots J)$ criteria/indicators as shown in Eq. (8). In which, x_{ij} presents the evaluation score of the ith alternative according to the jth criterion.

$$X = [x_{ij}]_{IxJ} \tag{8}$$

Step 2: Establish the normalized decision matrix according to Eq. (9).

$$y_{ij} = \begin{cases} \frac{x_{ij} - \min\limits_{1 \le i \le I}(x_{ij})}{\max\limits_{1 \le i \le I}(x_{ij}) - \min\limits_{1 \le i \le I}(x_{ij})}, & \text{if } jth \text{ is beneficial criterion} \\ \frac{\max\limits_{1 \le i \le I}(x_{ij}) - x_{ij}}{\max\limits_{1 \le i \le I}(x_{ij}) - \min\limits_{1 \le i \le I}(x_{ij})}, & \text{if } jth \text{ is non} - \text{beneficial criterion} \end{cases} \tag{9}$$

Step 3: The standard deviation of each criterion is calculated according to Eq. (10).

$$s_j = \sqrt{\frac{\left(\sum_{i=1}^{I} y_{ij} - \bar{y}_j\right)^2}{I-1}} \quad j = 1 \ldots J \tag{10}$$

where

$$\bar{y}_j = \frac{\sum_{i=1}^{I} y_{ij}}{I} \quad j = 1 \ldots J \tag{11}$$

Step 4: For each criterion, the Euclidean distance matrix between the alternatives' ratings is constructed according to (12) and (13).

$$D_j = \begin{bmatrix} 0 & d_{12}^j & \cdots & d_{1I}^j \\ d_{21}^j & 0 & \cdots & d_{2I}^j \\ \vdots & \vdots & \ddots & \vdots \\ d_{I1}^j & d_{I2}^j & \cdots & 0 \end{bmatrix} \quad j = 1 \ldots J \tag{12}$$

where

$$d_{ik}^j = |y_{ij} - y_{kj}| \quad j = 1 \ldots J;\ i = 1 \ldots I;\ k = 1 \ldots I;\ i \neq k \tag{13}$$

Step 5: Row mean, column mean, and matrix mean of each Euclidean distance matrix are determined using Eqs. (14)–(16).

$$\bar{R}^j = \frac{1}{I} \sum_{k=1,\, k \neq i}^{I} d_{ik}^j \quad j = 1 \ldots J;\ i = 1 \ldots I \tag{14}$$

$$\bar{C}^j = \frac{1}{I} \sum_{i=1,\, k \neq i}^{I} d_{ik}^j \quad j = 1 \ldots J;\ k = 1 \ldots I \tag{15}$$

$$\bar{M}^j = \frac{1}{I^2} \sum_{i=1}^{I} \sum_{k=1}^{I} d_{ik}^j \quad j = 1 \ldots J \tag{16}$$

Step 6: Each Euclidean distance matrix undergoes a double-centering procedure according to Eq. (17). For each criterion, double-centered matrices are created as the outcomes, as given in Eq. (18).

$$t_{ik}^j = d_{ik}^j - \bar{R}^j - \bar{C}^j + \bar{M}^j \quad j = 1 \ldots J;\ i = 1 \ldots I;\ k = 1 \ldots I \tag{17}$$

$$T_j = \begin{bmatrix} t_{11}^j & t_{12}^j & \cdots & t_{1I}^j \\ t_{21}^j & t_{22}^j & \cdots & t_{2I}^j \\ \vdots & \vdots & \ddots & \vdots \\ t_{I1}^j & t_{I2}^j & \cdots & t_{II}^j \end{bmatrix} \quad j = 1 \ldots J \tag{18}$$

Step 7: The following sub-steps are used to establish the distance covariance ($dCOV_{jj'}$) between the jth criterion and j'th criterion:

- Use the Hadamard product to elementally multiply double-centered matrices.
- Determine the elementwise multiplication matrix's average value.
- Determine the average value's square root.

Step 8: The distance variance of jth criterion ($dVAR_j = dCOV_{jj}$) is determined similarly to step 6.

Step 9: The distance correlation between the jth criterion and j'th criterion ($dCOR_{jj'}$) is determined according to Eq. (19).

$$dCOR_{jj'} = \frac{dCOV_{jj}}{\sqrt{dVAR_j \times dVAR_{j'}}} \tag{19}$$

Step 10: The information content of jth criterion (IC_j) is determined according to Eq. (20).

$$IC_j = s_j \sum_{j=1}^{I} \left(1 - dCOR_{jj'}\right) \quad j = 1 \ldots J \tag{20}$$

Step 11: The absolute weight of jth criterion (w_j) is determined according to Eq. (21).

$$w_j = \frac{IC_j}{\sum_{j=1}^{I} IC_j} \quad j = 1 \ldots J \tag{21}$$

EDAS and Fuzzy EDAS. Evaluation based on Distance from Average Solution (EDAS) is a decision-making method used to assess and rank alternatives in MCDM (Keshavarz Ghorabaee et al. 2015). It provides a systematic approach to determine the relative performance and suitability of alternatives based on their distances from the average solution. EDAS considers both the positive and negative aspects of criteria, allowing decision-makers to evaluate alternatives comprehensively. The following steps describe the process by which EDAS ranks alternatives.

Step 1: The average solution is determined based on the normalized decision matrix as Eq. (22).

$$\bar{y}_j = \frac{\sum_{i=1}^{I} y_{ij}}{I} \tag{22}$$

Step 2: The positive/negative distance from the average solution matrix is determined as Eqs. (23)–(24).

$$d_{ij}^{+} = \frac{\max\left(0, x_{ij} - \bar{y}_j\right)}{\bar{y}_j} \quad j = 1 \ldots J; i = 1 \ldots I \tag{23}$$

$$d_{ij}^{-} = \frac{\max\left(0, \bar{y}_j - y_{ij}\right)}{\bar{y}_j} \quad j = 1 \ldots J; i = 1 \ldots I \tag{24}$$

Step 3: The weighted total positive/negative distance from average solution are determined as Eqs. (25), (26).

$$s_i^{+} = \sum_{j=1}^{J} w_j d_{ij}^{+} \quad i = 1 \ldots I \tag{25}$$

$$s_i^{-} = \sum_{j=1}^{J} w_j d_{ij}^{-} \quad i = 1 \ldots I \tag{26}$$

Step 4: The alternative's appraisal score is defined as Eq. (27). The larger the appraisal score, the better the alternative.

$$as_i = \frac{1}{2}\left(\frac{s_i^{+}}{\max_i\left(s_i^{+}\right)} + \left(1 - \frac{s_i^{-}}{\max_i\left(s_i^{-}\right)}\right)\right) \quad i = 1 \ldots I \tag{27}$$

The EDAS method has also been extended and developed within the framework of fuzzy theory, resulting in the Fuzzy Evaluation based on the Distance from Average Solution (F-EDAS) approach (Ghorabaee et al. 2016). Fuzzy theory allows for the representation and handling of uncertainty and imprecision, which is particularly relevant in decision-making scenarios where criteria evaluations may involve subjective or linguistic assessments. In the F-EDAS method, the criteria evaluations and the average solution are represented using fuzzy numbers or linguistic terms (Le and Nhieu, 2022b). Fuzzy numbers enable decision-makers to express their preferences and judgments in a more flexible and nuanced manner. The fuzzy average solution is then calculated by aggregating the fuzzy evaluations for each criterion, incorporating the uncertainty inherent in the decision-making process. The development of F-EDAS within fuzzy theory enhances the EDAS method by incorporating the notion of fuzziness and capturing the inherent uncertainties in decision-making. By utilizing fuzzy numbers or linguistic terms, F-EDAS provides decision-makers with a more expressive and flexible representation of evaluations.

Numerical results

In this section, the proposed framework is applied to outline the overall picture of Fintech's influence and potential in the ASEAN region. This assessment process simultaneously considers two factors, including the current state of the technology infrastructure and enabling regulations. The assessment of the current state of financial activities and technology infrastructure is based on quantitative indicators. Meanwhile, the status of regulations is surveyed and quantified for assessment.

Financial activities and technology infrastructure (FA&TI) evaluation. To assess the impact of financial activities as well as technology infrastructure, this study uses six related indicators, which are described in detail below. The data of these indicators are collected based on open databases, which are provided by the World Bank, United Nations, and ASIAN Development Bank.

- Indicator 1 (I1) - GDP by financial and insurance activities (US$ million) (ADB Data Library, 2022): It measures the value of all final goods and services produced within an economy's financial and insurance sectors during a given period, typically a year. The term "at current market prices" indicates that the GDP calculation considers the prices of goods and services prevailing in the current period without adjusting for inflation. This means that the GDP figure reflects both changes in the volume of production within the financial and insurance sectors and any changes in prices over time. However, the open database only provides data in local currency. Therefore, through exchange rate data (ADB Data Library, 2022), the values of this indicator are converted to US$, as shown in Table 1.
- Indicator 2 (I2) - Money Supply (% of GDP at the current market) (ADB Data Library, 2022): this indicator refers to the total amount of money available in an economy at a given point in time. It represents the stock of currency, demand deposits (such as checking accounts), and other highly liquid assets held by individuals, businesses, and financial institutions.
- Indicator 3 (I3) - Secure Internet servers (per 1 million people) (World Bank Open Data, 2022): The number of distinct, publicly-trusted TLS/SSL certificates found in the Netcraft Secure Server Survey.
- Indicator 4 (I4) - Telecommunication Infrastructure Index 2022 (UN E-Government Knowledgebase, 2022): The index surveys the completion and modernity of infrastructure for the telecommunications sector.
- Indicator 5 (I5) - Online Service Index 2022 (UN E-Government Knowledgebase, 2022): This index evaluates the institutional framework, content provision, services provision, participation, and technology of online services.
- Indicator 6 (I6) - Individuals using the Internet (% of the population) (World Bank Open Data, 2022): Internet users are individuals who have used the Internet from any location. The Internet can be used via a computer, mobile

Table 1 GDP by Financial and Insurance Activities 2022 in ASEAN.

Country	GDP by Financial and insurance activities at current market prices in 2022 (local currency million)	Average exchange rate of 2022 (local currency - US$)	GDP by Financial and insurance activities at current market prices in 2022 (US$ million)
Brunei Darussalam	882.18	1.3615	647.94
Cambodia	6,095,250.42	4098.7	1487.11
Indonesia	736,188,800.00	14,308	51,452.43
Lao PDR	5,433,908.23	9698	560.32
Malaysia	107,593.82	4.14	25,968.16
Myanmar	392,660.80	1615.7	243.03
Philippines	1,961,921.52	49.25	39,832.25
Singapore	73,747.00	1.343	54,892.38
Thailand	1,339,071.00	31.98	41,875.94
Vietnam	387,838,031.60	23,160	16,746.19

Table 2 Decision matrix of indicators.

Country	Alpha-3 code	I1	I2	I3	I4	I5	I6
Brunei Darussalam	BRN	647.94	84.82	14,703.00	0.84	0.59	98
Cambodia	KHM	1487.11	143.83	651,189.00	0.56	0.42	60
Indonesia	IDN	51,452.43	46.36	4521.00	0.64	0.76	62
Lao PDR	LAO	560.32	74.99	1054.00	0.28	0.30	62
Malaysia	MYS	25,968.16	140.64	1016.00	0.79	0.76	97
Myanmar	MMR	243.03	60.04	308,704.00	0.61	0.31	44
Philippines	PHL	39,832.25	79.14	13,303.00	0.56	0.63	53
Singapore	SGP	54,892.38	137.70	796,767.00	0.88	0.96	91
Thailand	THA	41,875.94	148.70	243,223.00	0.73	0.78	85
Vietnam	VNM	16,746.19	159.58	438,126.00	0.70	0.65	74

Table 3 Euclidean distance matrix for GDP by financial activities (I1).

Country	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM	Row mean
BRN	0.000	0.015	0.930	0.002	0.463	0.007	0.717	0.993	0.754	0.295	0.418
KHM	0.015	0.000	0.914	0.017	0.448	0.023	0.702	0.977	0.739	0.279	0.411
IDN	0.930	0.914	0.000	0.931	0.466	0.937	0.213	0.213	0.175	0.635	0.541
LAO	0.002	0.017	0.931	0.000	0.465	0.006	0.719	0.994	0.756	0.296	0.419
MYS	0.463	0.448	0.466	0.465	0.000	0.471	0.254	0.529	0.291	0.169	0.356
MMR	0.007	0.023	0.937	0.006	0.471	0.000	0.724	1.000	0.762	0.302	0.423
PHL	0.717	0.702	0.213	0.719	0.254	0.724	0.000	0.276	0.037	0.422	0.406
SGP	0.993	0.977	0.213	0.994	0.529	1.000	0.276	0.000	0.238	0.698	0.592
THA	0.754	0.739	0.175	0.756	0.291	0.762	0.037	0.238	0.000	0.460	0.421
VNM	0.295	0.279	0.635	0.296	0.169	0.302	0.422	0.698	0.460	0.000	0.356
Column mean	0.418	0.411	0.541	0.419	0.356	0.423	0.406	0.592	0.421	0.356	0.434

phone, personal digital assistant, games machine, digital TV, etc.

Table 2 below presents the results of the data collection process of ASEAN countries according to the mentioned indicators. This is also considered the decision matrix for the multi-criteria evaluation process using the DCRITIC and EDAS methods, which are presented in the following section.

As mentioned above, the procedure of the DCRITIC method begins with normalizing the decision matrix as Eq. (9). Then, a standardized decision matrix is established. According to Eqs. (10), (11), the standard deviation for each indicator is determined. In the next step, for each indicator, the Euclidean distance matrix between the alternatives is constructed respectively according to Eqs. (12), (13). As a result, Tables 3 and 4 present the Euclidean distance matrix for the "GDP by financial activities" indicator (I1) and the "Money supply" indicator (I2), respectively. The Euclidean distance matrices for the remaining indicators are similarly calculated. The next process is double-centering those distance matrices according to Eqs. (14)–(18). In this process, elements have the row mean and column mean subtracted. After that, the mean value of the matrix is added to each element. The results of this process are double-centered distance matrices. As discussed above, the distance covariance of the two indicators is determined by three tasks: multiply their double-centered distance matrices by the Hadamard product, calculate the multiplied matrix's average value, and calculate the square root of this average value. These tasks are performed repeatedly for each pair of indicators. The results of the Hadamard product of I1 and itself are shown in Table 5. Meanwhile, Table 6 shows the Hadamard product's results of I1 and I2. Accordingly, the variance of the indicators and the covariance between the indicators are determined. As shown in

Table 4 Euclidean distance matrix for Money supply (I2).

Country	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM	Row mean
BRN	0.000	0.521	0.340	0.087	0.493	0.219	0.050	0.467	0.564	0.660	0.340
KHM	0.521	0.000	0.861	0.608	0.028	0.740	0.571	0.054	0.043	0.139	0.357
IDN	0.340	0.861	0.000	0.253	0.833	0.121	0.290	0.807	0.904	1.000	0.541
LAO	0.087	0.608	0.253	0.000	0.580	0.132	0.037	0.554	0.651	0.747	0.365
MYS	0.493	0.028	0.833	0.580	0.000	0.712	0.543	0.026	0.071	0.167	0.345
MMR	0.219	0.740	0.121	0.132	0.712	0.000	0.169	0.686	0.783	0.879	0.444
PHL	0.050	0.571	0.290	0.037	0.543	0.169	0.000	0.517	0.614	0.710	0.350
SGP	0.467	0.054	0.807	0.554	0.026	0.686	0.517	0.000	0.097	0.097	0.331
THA	0.564	0.043	0.904	0.651	0.071	0.783	0.614	0.097	0.000	0.096	0.382
VNM	0.660	0.139	1.000	0.747	0.167	0.879	0.710	0.097	0.096	0.000	0.450
Column mean	0.340	0.357	0.541	0.365	0.345	0.444	0.350	0.331	0.382	0.450	0.390

Table 5 The Hadamard product of the double-centered matrix for I1 and itself.

Country	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM
BRN	0.161	0.144	0.164	0.160	0.015	0.159	0.107	0.174	0.122	0.002
KHM	0.144	0.151	0.157	0.143	0.013	0.143	0.101	0.167	0.116	0.003
IDN	0.164	0.157	0.421	0.164	0.000	0.165	0.091	0.236	0.125	0.030
LAO	0.160	0.143	0.164	0.162	0.016	0.161	0.108	0.175	0.123	0.002
MYS	0.015	0.013	0.000	0.016	0.077	0.016	0.005	0.000	0.003	0.012
MMR	0.159	0.143	0.165	0.161	0.016	0.170	0.108	0.176	0.124	0.002
PHL	0.107	0.101	0.091	0.108	0.005	0.108	0.143	0.083	0.127	0.009
SGP	0.174	0.167	0.236	0.175	0.000	0.176	0.083	0.561	0.116	0.034
THA	0.122	0.116	0.125	0.123	0.003	0.124	0.127	0.116	0.167	0.014
VNM	0.002	0.003	0.030	0.002	0.012	0.002	0.009	0.034	0.014	0.077

Table 6 The Hadamard product of the double-centered matrix for I1 and I2.

Country	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM
BRN	0.116	−0.082	−0.061	0.091	0.025	0.070	−0.082	0.078	0.081	−0.012
KHM	−0.082	0.125	0.140	−0.105	−0.033	−0.125	0.081	−0.099	−0.104	0.015
IDN	−0.061	0.140	0.448	−0.106	0.001	−0.193	0.063	−0.158	−0.131	0.069
LAO	0.091	−0.105	−0.106	0.137	0.033	0.115	−0.094	0.104	0.103	−0.014
MYS	0.025	−0.033	0.001	0.033	0.083	0.039	−0.018	−0.004	0.014	0.026
MMR	0.070	−0.125	−0.193	0.115	0.039	0.205	−0.077	0.127	0.122	−0.016
PHL	−0.082	0.081	0.063	−0.094	−0.018	−0.077	0.117	−0.065	−0.097	0.029
SGP	0.078	−0.099	−0.158	0.104	−0.004	0.127	−0.065	0.203	0.077	−0.054
THA	0.081	−0.104	−0.131	0.103	0.014	0.122	−0.097	0.077	0.153	−0.041
VNM	−0.012	0.015	0.069	−0.014	0.026	−0.016	0.029	−0.054	−0.041	0.141

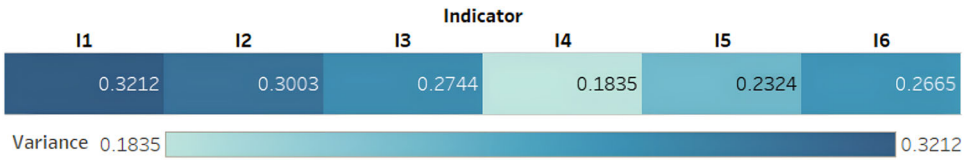

Fig. 3 The variance of indicators. The variance of financial activities and technology infrastructure indicators across ASEAN by DCRITIC method.

Fig. 3, the telecommunication infrastructure index (I4) has the lowest variance and contrasts with GDP by financial and insurance activities (I1). This result implies that ASEAN countries do not have technical infrastructures that are too different, while the contribution of financial activities is significantly different. Furthermore, as shown in Table 7, the correlation coefficient of GDP by financial and insurance activities (I1) and Online Service Index (I5) has a much higher value than it and the rest of the indicators.

Based on the correlation of the indicators, the DCRITIC method determined their information contents according to Eq. (20). The larger the correlation, the lower the information content. A snapshot and a schematic of the information contents are shown in Fig. 4. It shows that indicator one and indicator 3 provide more information content compared to others. Therefore, according to Eq. (21), indicator 1 (GDP by financial and insurance activities) and indicator 3 (Secure Internet servers) take more weight in the evaluation process, as shown in Fig. 5. It is followed by indicator 2 (Money Supply) and indicator 6 (Individuals using the Internet) with weights of 17% and 15%, respectively. The lower weights are indicator 4 (telecommunication infrastructure index) and indicator 5 (Online service Index), with 12% each. After the weights of the indicators are determined by DCRITIC, another distance-based method is applied to

evaluate the FA&TI scores of ASEAN countries. As described in "EDAS and fuzzy EDAS", the EDAS method first determines the average solution based on the decision matrix normalized by Eq. (22). Then, according to Eqs. (23), (24), the possible/negative distance matrices from the average solution for FA&TI indicators are constructed. Based on these results and the weights of the indicators, the appraisal scores on financial activities and technology infrastructure of ASEAN countries are calculated using Eq. (27).

The overview of FA&TI in ASEAN is shown in Fig. 6. There are five groups defined by the calculated appraisal scores. According to the evaluation results, Singapore is the leader in financial activities and technology infrastructure in ASEAN. Singapore has long been recognized as a prominent financial hub in the region. It boasts a robust financial sector, advanced technological infrastructure, and a conducive business environment. The city-state has attracted numerous multinational companies, financial institutions, and technology firms, making it a highly competitive and innovative hub for finance and technology. The rapidly growing group includes Vietnam and Thailand, which are experiencing rapid growth in their financial activities and technology infrastructure. Both countries have been investing heavily in upgrading their technological capabilities and expanding their financial sectors. Vietnam has witnessed significant economic growth in recent years, attracting foreign investments and fostering a vibrant startup ecosystem. The intermediate level of FA&TI includes Cambodia and Malaysia. Although not at the forefront like Singapore, these countries have made notable progress in developing their financial activities and technology infrastructure. Cambodia has been actively working to strengthen its financial sector, while Malaysia has established itself as a regional Islamic finance hub and has a well-developed technology ecosystem. The next group includes Indonesia, the Philippines, and Brunei Darussalam, which have relatively lower FA&TI scores compared to the previous groups. However, these countries are still making efforts to enhance their financial activities and technology infrastructure. Indonesia, with its large population and growing digital economy, has been implementing various initiatives to promote financial inclusion and develop its fintech sector. The Philippines has also been focusing on expanding its digital financial services, while Brunei Darussalam has been investing in upgrading its technological capabilities. Lastly, Myanmar and Lao PDR are mentioned as the countries with the lowest FA&TI scores. These countries are facing

Table 7 The correlation coefficient matrix of indicators.

Indicator	I1	I2	I3	I4	I5	I6
I1	1.000	0.351	0.321	0.438	0.849	0.341
I2	0.351	1.000	0.619	0.534	0.496	0.601
I3	0.321	0.619	1.000	0.367	0.403	0.317
I4	0.438	0.534	0.367	1.000	0.731	0.885
I5	0.849	0.496	0.403	0.731	1.000	0.649
I6	0.341	0.601	0.317	0.885	0.649	1.000

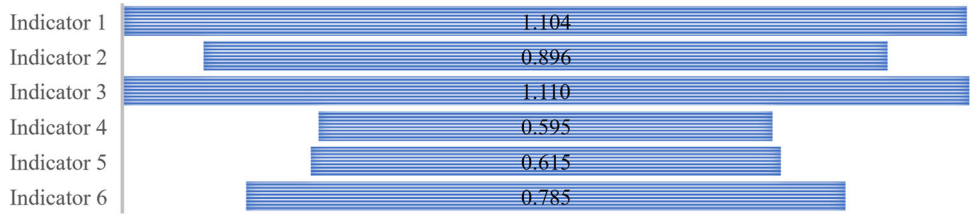

Fig. 4 Information content of indicators by DCRITIC method. The amount of information content of indicators is determined by the DCRITIC method.

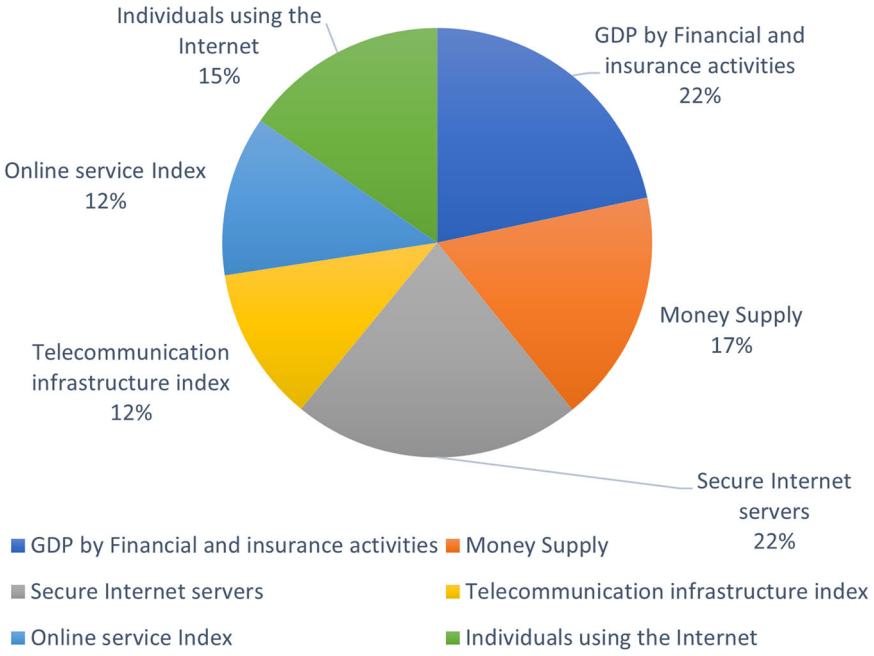

Fig. 5 Indicator weights by indicators by DCRITIC method. The relative weights of indicators for fintech assessment by the DCRITIC method.

Fig. 6 The appraisal scores on FA&TI in ASEAN. The comparative appraisal scores for financial activities and technology infrastructure (FA&TI) across ASEAN countries.

challenges in terms of developing their financial activities and technology infrastructure due to various factors, including limited resources, infrastructure gaps, and political instability.

Fintech-enabling regulation (FER) evaluation. Besides FA&TI, fintech-enabling regulations (FERs) are essential for fostering innovation, enhancing financial inclusion, protecting consumers, mitigating risks, attracting investments, promoting collaboration, and facilitating cross-border activities. By creating a supportive regulatory environment, countries can harness the potential of fintech to drive economic growth, improve financial services, and promote financial well-being for individuals and businesses. To assess the status of FERs in ASEAN, this study first identifies key regulations that promote the development of the fintech sector. The list is described as follows. The Anti-Money Laundering (R1) rules require them to detect and report suspicious activities. Equity crowdfunding (R2) regulations ensure transparency and investor protection. Digital ID (R3) regulations focus on secure digital identity verification. Electronic money (R4) rules protect consumers and prevent financial crime. Cybersecurity (R5) measures are essential to safeguard customer data. Electronic payment/Transactions (R6) regulations aim for secure digital fund transfers. Cryptocurrency (R7) rules address the use and exchange of digital currencies. Data protection (R8) regulations safeguard personal information. Innovation facilitators (R9) aim to support Fintech innovation. Digital banking (R10) regulations cover online banking services, emphasizing safety and privacy. Survey information on the status of each ASEAN country with each key regulation was collected mainly according to the World Bank Global Fintech-enabling regulations database (Global Fintech-enabling regulations database, 2023). The collection results are presented in Tables 8 and 9.

To assess the status of FERs in the ASEAN, a detailed analysis was conducted using a multi-level classification system. The completion levels of FERs were categorized into five groups: unregulated, sandboxed, guided by other laws, draft laws, and laws. However, to quantify this qualitative information, fuzzy theory was applied to provide a more precise assessment. The status levels of FERs in ASEAN and the TFN were compiled and presented in Table 10, allowing for a comparative analysis. To further evaluate the data, a fuzzy decision matrix was established.

This matrix, constructed using the adapted EDAS method for a fuzzy environment, lacks key regulation weights due to limited data. The fuzzy average solution provides an overall view of FERs in ASEAN. Positive and negative distances from this solution were calculated using the same method as EDAS and then converted into clear figures for assessing variations among ASEAN countries. Appraisal scores for FERs are standardized with equal weights, though future research should explore more nuanced weighting methods. The appraisal scores offer insights into ASEAN regulatory environments, as seen in Fig. 7.

The first group comprises countries with high appraisal scores, indicating a well-developed and conducive regulatory environment for Fintech. Singapore stands out as the leader, known for its robust Fintech ecosystem and regulatory framework. The Philippines, Thailand, and Malaysia have also made significant progress, implementing comprehensive regulations to foster Fintech innovation and digital transformation in their financial sectors. The second one includes Indonesia, Lao PDR, and Brunei Darussalam. These countries have achieved moderate appraisal scores, suggesting a significant level of development in their

Table 8 Fintech-enabling regulation status in ASEAN.

Country	Key regulation				
	Anti-money laundering	**Equity crowdfunding**	**Digital ID**	**Electronic money**	**Cybersecurity**
BRN	Anti-money Laundering law	Regulated under the framework created for this activity	National Registration Regulations, Arts 4, and 5	No legislation identified	Computer Misuse Order, 2000
KHM	Law on Anti-Money Laundering and Combating the Financing of Terrorism	No legislation identified	Sub Decree National Identity Cards No. 60 2007, Art. 4	No legislation identified	Law on Telecommunications
IDN	Law 8/2010 on Prevention and Eradication of Money Laundering; Law 9/2013 on Prevention and Eradication of Terrorism Funding	No legislation identified	Administration of Population Law, Art. 2	Regulation No. 20/6/ PBI/2018 on Electronic Money	The Electronic Transaction and Information Law
LAO	Law No.49/NA on Anti-Money Laundering and Combatting the Financing of Terrorism ("AML Law")	No legislation identified	Family Registration Law, as amended, 2009, Art. 16	Lao PDR on The Promulgation of the Law on Payment System	The Law on Prevention and Combating Cyber Crime
MYS	Anti-Money Laundering, Anti-Terrorism Financing and Proceeds of Unlawful Activities Act 2001	Regulated under the framework created for this activity	No legislation identified	Payment Systems Act 2003	Computer Crime Act 1997
MMR	The Anti-Money Laundering Law	No legislation identified	No legislation identified	No legislation identified	Electronic Transaction Act
PHL	Anti-Money Laundering Act of 2001 (RA 9160)	No legislation identified	Philippine Identification System Act. (Republic Act No. 11055)	Regulations on Electronic Banking Services	Cyber Crime Prevention Act (RA 10175)
SGP	Terrorism (suppression of financing) Act. 16 of 2022	Regulated under the framework created for this activity	No legislation identified	Major Payment Institution License under the Payment Services Act	Computer Misuse and Cybersecurity Act (Chapter 50 A)
THA	Anti-Money Laundering Act B.E. 2542 (1999)	Regulated under the framework created for this activity	Digital Identification Act	Payment Systems Act B.E. 2560 (2017)	Computer Crime Act. 2017
VNM	Law of prevention of money	No legislation identified	Decree No. 05/1999/ ND-CP on the People's Identity Card, Arts 2 and 3	No legislation identified	Law on Information Technology Vietnam

Table 9 Fintech-enabling regulation status in ASEAN (cont).

Country	Key regulation				
	Electronic transactions	Cryptocurrency	Data protection	Innovation facilitators	Digital banking
BRN	Electronic Transactions Act 2008. Electronic Transactions Order 2000	No legislation identified	No legislation identified	Sandbox	Regular banking
KHM	Law on E-commerce, promulgated by Royal Code No. NS/RKM/1119/017	No legislation identified	No legislation identified	No legislation identified	Regular banking
IDN	Electronic Information and Transaction Draft Law 11 of 20088	No legislation identified	Draft Bill on the Protection of Private Personal Data	Sandbox	Regular banking
LAO	Law on Electronic Transactions	No legislation identified	Law on the Protection of Electronic Data (No. 25/NA, 12 May 2017)	No legislation identified	Regular banking
MYS	Digital Signature Act 1997	No legislation identified	Personal Data Protection Act 2010	Sandbox	Digital banking
MMR	Electronic Transactions Law (The State Peace and Development Council Law No. 5/2004)	No legislation identified	No legislation identified	No legislation identified	Regular banking
PHL	Electronic Commerce Act of 2001	Digital Asset Token Offering (DATO)	Data Protection Legislation 2012	Sandbox	Digital banking
SGP	Electronic Transaction Act Chapter 88	Securities and Futures Act. Payment services Act	Personal Data Protection Act of 2012	Sandbox	Digital banking
THA	Electronic Transaction Act (No.2) B.E. 2551 (2008)	No legislation identified	Personal Data Protection Act B.E. 2562 (2019)	Sandbox	Regular banking
VNM	Law on E-Transactions (No. 51/2005/QH11)	No legislation identified	Draft Decree on Personal Data Protection	No legislation identified	Regular banking

Table 10 Fintech-enabling regulation status and corresponding TFN.

Regulation status	Triangular fuzzy number
No legislation identified	(1, 1, 3)
Sandbox	(1, 3, 5)
Guided by other laws	(3, 5, 7)
Draft law	(5, 7, 9)
Law	(7, 9, 9)

Fintech-enabling regulations. While they may not be on par with the high-performing group, they have made notable strides in establishing regulatory frameworks to support Fintech growth. This indicates a positive commitment toward fostering innovation in the financial sector and encouraging Fintech adoption. Lastly, Vietnam, Cambodia, and Myanmar have obtained relatively low appraisal scores, indicating that their Fintech-enabling regulations are still in the early stages of development or require significant improvement. Vietnam and Cambodia have shown some progress but still have room for enhancement in establishing comprehensive frameworks. Myanmar, on the other hand, has a minimal appraisal score, highlighting the urgent need for the country to prioritize the development of Fintech regulations. The appraisal scores highlight the varying levels of progress and maturity of Fintech-enabling regulations across ASEAN countries. While some countries have established robust frameworks that promote Fintech innovation and digital transformation, others are still in the early stages of developing comprehensive regulations.

FA&TI versus FERs in ASEAN. As shown in Fig. 8, the appraisal scores on FA&TI and FERs offer insights into the relationship between these two dimensions in ASEAN countries. Among the countries assessed, Singapore emerges as the leader, with a perfect score in FA&TI (1.0000) and a very high score in FERs (0.8934). It showcases a highly developed financial ecosystem, advanced technology infrastructure, and a robust regulatory framework for Fintech. The Philippines also demonstrates significant progress in FERs (0.8027) and moderate development in FA&TI (0.3100), signaling a commitment to fostering Fintech innovation. Thailand (FERs: 0.7619), Malaysia (FERs: 0.6379), and Indonesia (FERs: 0.5357) showcase varying degrees of progress in FERs, with Malaysia displaying a higher score in FA&TI (0.5167). Brunei Darussalam (FERs: 0.4084) and Cambodia (FERs: 0.1544) have made some strides in FERs but require improvements in FA&TI. Lao PDR (FERs: 0.5079) and Vietnam (FERs: 0.2797) demonstrate potential in FERs but need to enhance their financial activities and technology infrastructure. Lastly, Myanmar (FERs: 0.0025) lags in both dimensions and requires substantial development efforts. These results emphasize the need for countries to focus on enhancing their financial activities, technology infrastructure, and Fintech-enabling regulations to foster innovation, drive economic growth, and accelerate digital transformation in the ASEAN region.

Conclusion

This study provides a comprehensive assessment of Fintech's influence and potential in ASEAN countries. It highlights the crucial role played by Fintech in driving economic growth, enhancing trade relationships, and contributing to regional and global prosperity. The evaluation of financial activities, technology infrastructure, and Fintech-enabling regulations reveals varying levels of development across the ASEAN region. Singapore

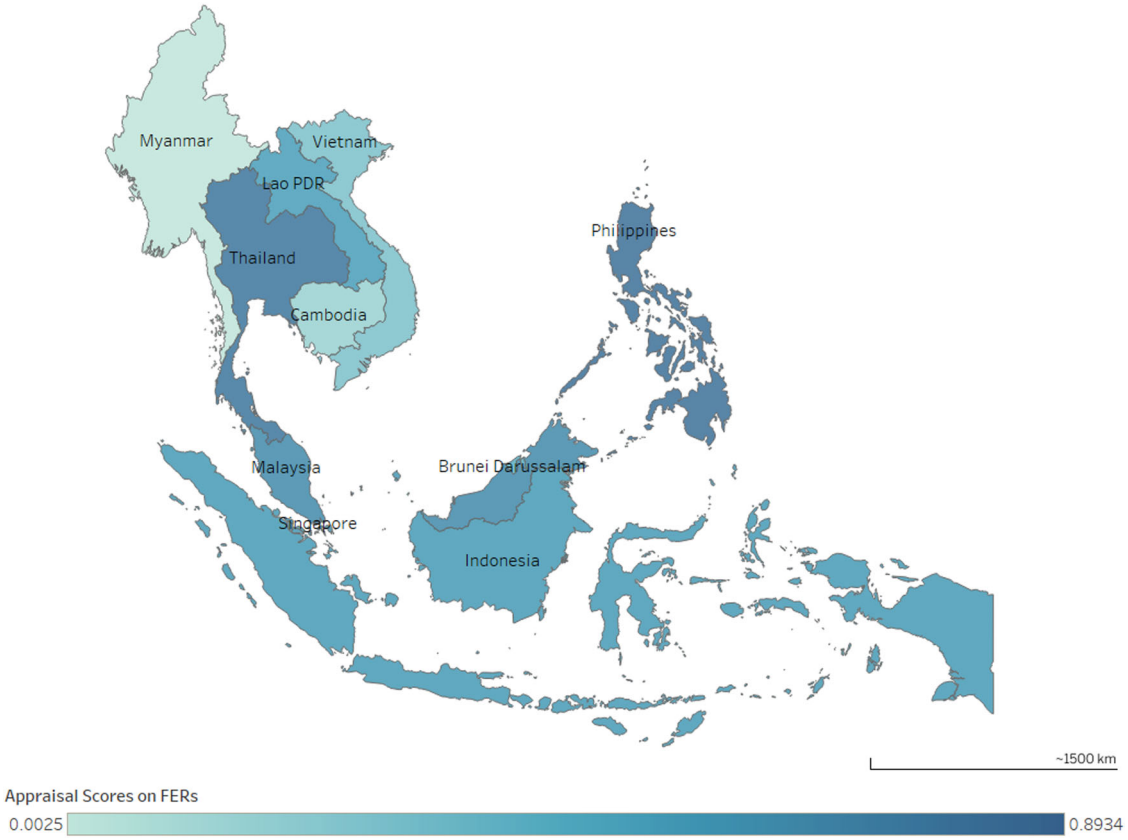

Fig. 7 The appraisal scores on FERs in ASEAN. The comparative appraisal scores for fintech-enabling regulations (FERs) across ASEAN countries.

emerges as a leader, showcasing a highly developed financial ecosystem, advanced technology infrastructure, and a robust regulatory framework for Fintech. The Philippines also demonstrates significant progress in Fintech-enabling regulations, while Thailand, Malaysia, and Indonesia showcase varying degrees of advancement in this area. Brunei Darussalam and Cambodia have made strides in Fintech-enabling regulations but require improvements in financial activities and technology infrastructure. Lao PDR and Vietnam demonstrate potential in Fintech-enabling regulations but need to enhance their financial activities and technology infrastructure to fully leverage Fintech's benefits. Myanmar lags behind in both dimensions and requires substantial development efforts to catch up with other ASEAN countries.

In addition to the aforementioned factors, another crucial method used in this study is the DCRITIC method. This method not only determines the weight of the criteria but also prioritizes the alternatives based on the correlation of numerical data. By applying the DCRITIC method, this study introduces a robust decision-making framework that combines both numerical and linguistic assessments. The incorporation of the F-EDAS approach further enhances the analysis of Fintech-enabling regulations. This method quantifies and analyzes linguistic assessments, allowing for a comprehensive evaluation of the regulatory landscape in ASEAN countries. By utilizing fuzzy theory to quantify qualitative information, the study provides a more nuanced understanding of the status of Fintech-enabling regulations in the region. The combination of the DCRITIC method and the F-EDAS approach in this study offers a holistic perspective on the influence of financial activities, technology infrastructure, and Fintech-enabling regulations. It enables policymakers and stakeholders to make informed decisions based on a comprehensive assessment of multiple criteria and linguistic assessments. The utilization of the DCRITIC method and the F-EDAS approach contributes to the theoretical framework of decision-making in the context of Fintech development. This innovative approach allows for a more comprehensive evaluation of the factors influencing Fintech's impact in ASEAN countries, providing valuable insights for policymakers, researchers, and industry players in the region.

The findings underscore the importance of enhancing financial activities, technology infrastructure, and Fintech-enabling regulations in ASEAN. Governments and policymakers should prioritize creating a supportive environment for Fintech innovation, which will spur economic growth, attract investments, and foster digital transformation. By focusing on these areas, ASEAN countries can harness the full potential of Fintech, strengthen their positions in the global economy, and promote inclusive and sustainable development in the region.

This study contributes to the literature on Fintech's role in regional economic integration by introducing a novel evaluative framework that combines the DCRITIC and Fuzzy EDAS methods. Theoretically, it advances our understanding of how financial technology can be assessed and ranked across different economies. It underscores the importance of a holistic approach in evaluating the impact of financial activities and regulatory environments on Fintech development and highlights the complex interplay between technological infrastructure and enabling regulations in different national contexts. Practically, this research offers valuable insights for policymakers and financial institutions in ASEAN. The findings illuminate the strengths and weaknesses of each country's FA&TI and FERs, serving as a benchmark for ongoing improvements and investments. The high scores of countries like Singapore provide a model for others to emulate, while the lower scores indicate areas where policy interventions, infrastructure development, and regulatory reforms are urgently needed to foster Fintech growth.

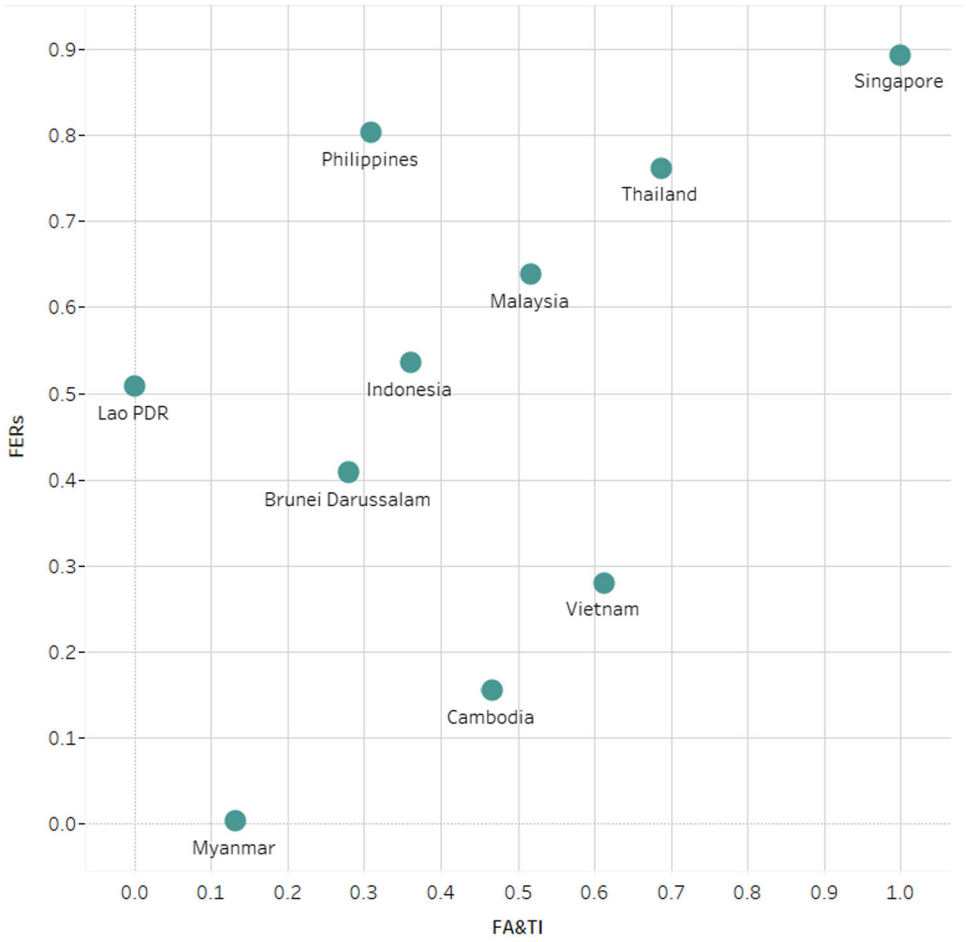

Fig. 8 The Fintech FA&TI-FERs positioning in ASEAN. The positioning map of ASEAN countries is based on fintech FA&TI and FERs appraisal scores.

This study is not without limitations. The data used for the DCRITIC and Fuzzy EDAS methods, while current, are subject to the rapid changes characteristic of the Fintech sector. Furthermore, the choice of indicators, while comprehensive, may not capture all nuances of Fintech development. The reliance on secondary data sources also introduces potential biases, as the data may not fully reflect ground realities or the latest regulatory changes. Future research should consider longitudinal studies to track the progress of Fintech in ASEAN over time, taking into account the dynamic nature of financial technologies and regulations. Incorporating primary data through expert interviews or surveys could enrich the analysis and mitigate the limitations associated with secondary data. Expanding the framework to include additional indicators, such as consumer adoption rates or the quality of digital financial services, could provide a more granular understanding of the ecosystem. Finally, comparative studies with other regions could offer a global perspective on Fintech's development and its role in economic growth.

Data availability

All data generated or analyzed during this study are included in this published article.

Received: 31 October 2023; Accepted: 15 December 2023;
Published online: 12 January 2024

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Acknowledgements

This research work was partially supported by the National Science and Technology Council, Taiwan, under Grant no.: NSTC 112-2622-E-992-014.

Author contributions

These authors contributed equally to this work.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Ethical approval

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

Informed consent

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

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-023-02581-2.

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