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Joni Fat
Universitas Trisakti, Jakarta, jonif@ft.untar.ac.id

Parwadi Moengin
Universitas Trisakti, Jakarta, parwadi@trisakti.ac.id

Pudji Astuti
Universitas Trisakti, Jakarta, pudji@trisakti.ac.id

Sally Cahyati
Universitas Trisakti, Jakarta, sally@trisakti.ac.id

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SUSTAINABILITY IN FOREX TRADING: A REVIEW IN SEARCH OF THE SARSA-FIS HYBRID METHOD AS A NOVELTY

Joni Fat*, Parwadi Moengin**, Pudji Astuti***, and Sally Cahyati****

* Doctoral Student, Department of Industrial Engineering, Universitas Trisakti, Jakarta, Indonesia.
Electrical Engineering Program, Universitas Tarumanagara, Jakarta, Indonesia.
Email: jonif@ft.untar.ac.id
** Corresponding Author, Professor, Department of Industrial Engineering, Universitas Trisakti.
Jakarta, Indonesia. Email: parwadi@trisakti.ac.id
*** Department of Industrial Engineering, Universitas Trisakti, Jakarta, Indonesia.
Email: pudji@trisakti.ac.id
**** Department of Industrial Engineering, Universitas Trisakti, Jakarta, Indonesia.
Email: sally@trisakti.ac.id

ABSTRACT

This study employs meta-analysis, rich pictures, timeline analysis, and causal loop diagram to explore the sustainability impacts of the SARSA-FIS hybrid method in forex trading robots. It reviews 56 references (2018-2023), using rich pictures to map AI-driven interactions. Timeline analysis traces AI's evolution in forex, while causal loop diagram clarifies its role in market dynamics. Responsible algorithms and SRI principles mitigate risks, promoting ethical trading. SARSA-FIS enhances strategies, leveraging AI for sustainable forex practices amidst global uncertainties. The research identifies gaps and positions SARSA-FIS as a novel approach, providing a foundation for advancing AI applications in finance, particularly in forex trading.

Keywords: AI; Forex trading robots; Sustainability; SARSA-FIS.
JEL Classification: G17; C45; D81; E37.

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I. INTRODUCTION

The Sustainable Development Goals (SDGs) established by the United Nations in 2015 serve as a universal call to action to end poverty, protect the planet, and ensure prosperity for all by 2030 (Kleespies and Dierkes, 2022). Among these goals, SDG 8: Decent Work and Economic Growth, and SDG 9: Industry, Innovation, and Infrastructure are particularly pertinent to the discourse on financial technology and economic development. The integration of advanced technologies, such as Artificial Intelligence (AI) and hybrid methods, into forex trading systems directly intersects with these goals. SDG 8 emphasizes promoting sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all (Küfeoğlu, 2022).

The focus on forex trading robots and AI within the financial sector contributes to economic activities by enhancing decision-making and trading efficiency, which supports economic development by improving financial stability and growth (Nneka Adaobi Ochuba *et al.*, 2024). Moreover, while automation in trading can impact traditional job roles, it creates new high-skilled employment opportunities in technology development and management, potentially leading to broader economic benefits and job creation. SDG 9 aims to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation (Kleespies and Dierkes, 2022).

The application of AI and hybrid methods in forex trading represents a significant leap in financial technology innovation (Qin *et al.*, 2023). Although the primary focus is not on physical infrastructure, the advancement and reliance on robust digital infrastructure are crucial for supporting these sophisticated trading systems. Enhancements in digital infrastructure facilitate further innovation and improvements, reinforcing the objectives of fostering industry innovation and development. Thus, the topic of "Sustainability of Forex Trading Robot SARSA-FIS Hybrid Method: Leveraging Artificial Intelligence for Enhanced Decision-Making Amid Global Uncertainty - A Review" aligns well with the themes of SDG 8 and SDG 9. The article addresses how AI-driven forex trading systems can drive economic growth, enhance job creation in high-tech sectors, and support the development of innovative digital infrastructures. By examining the sustainability and effectiveness of these technologies, the article contributes to the broader conversation on achieving the SDGs through technological advancement and economic innovation.

Before delving deeper into the main topic, it is imperative to clarify the key terms used in the title: sustainability, forex trading robots, and risk management. These terms will be defined in accordance with the specific focus of the article. Providing clear definitions for these concepts is paramount for comprehending the subsequent discussions and analyses.

Sustainability remains a dynamic concept, subject to ongoing debates and discussions concerning its interpretation and application across diverse contexts (Ruggerio, 2021). Broadly delineated, sustainability entails the capacity to uphold ecological equilibrium and satisfy present needs without compromising the ability of future generations to meet their own requirements (Ruggerio, 2021). This concept often poses a challenge for researchers due to its ambiguous and polysemous nature (Salas-Zapata and Ortiz-Muñoz, 2019). At its essence,

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sustainability involves the integration of socio-environmental criteria into human actions related to products or processes, thereby implying a relationship between humans and ecosystems within socio-ecological systems (Salas-Zapata and Ortiz-Muñoz, 2019). It represents a multidimensional construct that includes economic, social, environmental, and technological dimensions (Rosen, 2018). Sustainability signifies a progression towards enhancement that safeguards long-term well-being while conserving resources for future generations (Rosen, 2018).

Moreover, sustainability refers to the fair, ethical, and efficient use of natural resources to meet the needs of current and future generations while enhancing overall well-being (Sakalasooriya, 2021). It denotes managing resources to maintain socio-ecological balance, ensuring present needs are met without harming the capacity of future generations to meet theirs (Dixit and Chaudhary, 2020). Sustainability integrates human actions with socio-environmental criteria, embodying the interconnection between humans and ecosystems. It represents a multidimensional paradigm encompassing economic, social, environmental, and technological facets, striving for the just, ethical, and efficient utilization of natural resources for the betterment of current and future generations. The key points regarding the term sustainability can be summarized as follows:

I. Maintaining ecological balance and meeting present needs without compromising the capacity of future generations.
II. Integrating socio-environmental criteria into human actions, reflecting the relationship between humans and ecosystems.
III. A multidimensional concept encompassing economic, social, environmental, and technological factors.
IV. Fair, ethical, and efficient use of natural resources for the well-being of current and future generations.

Thus, sustainability can be defined as a concept that refers to maintaining socio-ecological balance to meet present needs without jeopardizing future generations through integration into human actions and the fair, ethical, and efficient utilization of natural resources. Furthermore, sustainability is defined to align with the needs of this topic, namely the concept of managing systems to achieve current profit without sacrificing market stability and future profit opportunities, considering socio-ecological impacts through ethical, fair, and efficient strategies.

On the other hand, forex trading robots, also known as expert advisors (EAs) or trading robots, represent a pivotal development in the realm of financial technology. These sophisticated computer programs are meticulously crafted to navigate the complexities of the forex market, executing transactions with precision and efficiency. Operating autonomously, these robots adhere to predefined rules and parameters, ensuring consistency and objectivity in their decision-making processes (Rundo, 2019). For example, an EA can swiftly open positions, set precise Take Profit and Stop Loss levels, and efficiently manage trades, all without human intervention (Primadigantari *et al.*, 2022).

The advent of automated trading, often termed algorithmic trading, has revolutionized the dynamics of financial markets. Through the utilization of meticulously designed algorithms, automated trading systems swiftly execute a plethora of transaction orders, fostering a seamless and rapid-paced trading environment (Huang *et al.*, 2019). This integration of technology within financial systems transcends mere efficiency; it embodies a paradigm shift towards real-time decision-making, encapsulated within the framework of Enterprise Information Systems (EIS) (Huang *et al.*, 2019). As these automated systems continue to evolve, they progressively replace human involvement in the trading process. By harnessing predefined parameters and algorithmic logic, automated trading systems autonomously navigate market fluctuations, optimizing transaction execution and minimizing the potential for human error (Todorović *et al.*, 2019). Algorithmic Trading (AT) epitomizes this evolution, encompassing a spectrum of automated transaction strategies meticulously crafted to respond to specific market variables, including time, price, volume, and historical patterns (Hilbert and Darmon, 2020). The key points regarding Forex trading robots can be summarized as follows:

1. Automated Forex Trading Program: A computer program designed to execute forex transactions automatically.
2. Order Management: The program can create, set, and close orders based on market conditions.
3. Predefined Parameters: The automated trading system makes transaction decisions based on predefined parameters.
4. Real-Time Analysis: Continuously analyzes market conditions in real-time to ensure optimal transaction execution.

So, Forex trading robots are computer programs that automatically perform forex transactions by creating, setting, and closing orders based on market conditions. These robots operate without the need for manual intervention, making decisions based on predefined parameters. They are designed to continuously analyze market conditions in real-time, ensuring that transactions are executed optimally. By leveraging advanced algorithms and data-driven strategies, forex trading robots provide consistency, objectivity, and efficiency in trading operations. As a result, they serve as valuable tools for traders, enabling them to navigate the dynamic forex market with greater confidence and precision.

Amidst the backdrop of rapid technological advancements, the sustainability of forex trading robots emerges as a pivotal area of inquiry. In an era marked by global uncertainty and rapid technological evolution, understanding the implications of integrating artificial intelligence into automated trading systems becomes paramount. This review aims to delve into the intricate relationship between automated trading systems, artificial intelligence, and sustainability within the dynamic realm of the forex market. By exploring the ethical, economic, and ecological dimensions, this review seeks to shed light on the potential of forex trading robots to promote sustainable trading practices amidst the ever-evolving market dynamics.

The remainder of this paper is as follows. Section II presents the Data and Methodology, including the dataset description and the structured approach used to collect, filter, and analyze the references. Section III presents the main findings, including the use of overlay diagrams for visualizing machine learning trends in forex robot trading and the integration of sustainability principles in AI-driven trading systems. The study highlights advancements in AI methodologies, emphasizing adaptive, efficient, and sustainable approaches to enhance trading performance, and the Section IV concludes the paper.

II. DATA AND METHODOLOGY

A. Dataset

The dataset consists of 56 references, with an overall count of 92 references when considering repeated citations per topic term, sourced from various academic databases and platforms such as connectedpapers.com, Publish or Perish, sciencedirect.com, academia.edu, proquest.com, dimensions.ai, and scholar.google.com. These references were obtained using relevant keywords related to sustainability and forex, machine learning and forex, artificial intelligence and forex, forex trading robots, risk management and forex, and portfolio and forex. To ensure the credibility of the publications, the reference list underwent further evaluation using scimagojr.com, a platform known for assessing journal impact factors.

Table 1.
Topics Overview for References

This table summarizes the number of articles and their impact factors for various topics across different years. The topics include Sustainability and Artificial Intelligence (AI). The impact factors are classified as Q1, Q2, and Q3, where available, indicating the quality and relevance of the journals in which the articles were published.

Topic	Year	Number of Articles	Impact Factor
Sustainability	2019	1	-
	2021	1	-
	2022	2	Q1
	2023	2	-
Artificial Intelligence (AI)	2018	3	Q1
	2019	11	Q1, Q2
	2020	8	Q1, Q2
	2021	7	Q1, Q2, Q3
	2022	12	Q1, Q2, Q3
	2023	9	Q1, Q2

From the references gathered, a meta-analysis was performed to customize them according to the specific topic requirements, leading to a narrowed-down selection of 50 references focused on AI. These references cover the period from 2018 to 2023, with significant clusters observed in 2019 and 2022. The selection comprises articles from different quartiles, reflecting a diverse collection of publications with varying levels of scholarly influence. Additionally, the dataset includes 7 articles focusing on sustainability within the context of forex trading. These articles were published between the years 2019 and 2023, showcasing a growing interest in the intersection of sustainability principles and financial markets. Notably, while some articles lacked quartile information, others were categorized within the first quartile, indicating a certain level of scholarly recognition. Table 1 detailing the topics of Sustainability and AI listing the years, number of articles, and impact factors of the journal articles.

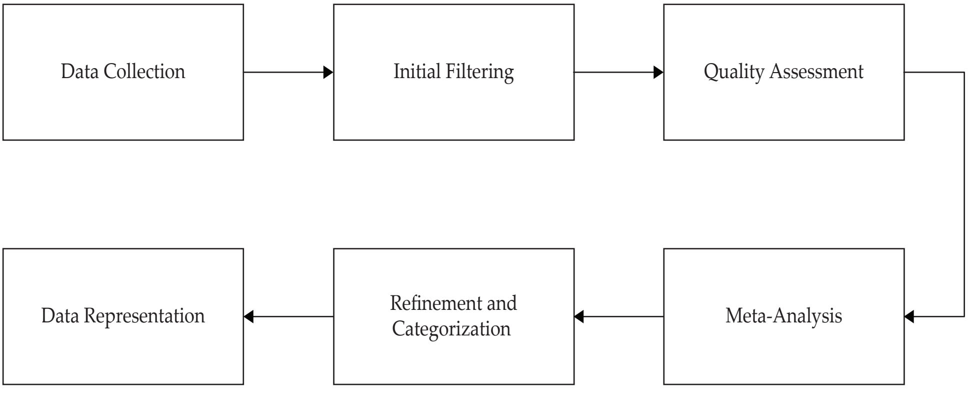
B. Methodology

The methodology described ensured a systematic and rigorous approach to collecting, filtering, assessing, and analyzing literature relevant to the study's objectives, thereby enhancing the reliability and validity of the findings. Additionally, a methodological diagram (Figure 1) was included to visually represent the sequential flow of the methodology, depicting the progression from data collection to data representation. This comprehensive approach facilitated a thorough examination of the literature related to the identified topics in forex trading, ultimately contributing to a robust and insightful analysis. Below are the stages of the methodology utilized.

1. Data collection: A total of 92 references were gathered from various academic databases and platforms, including connectedpapers.com, Publish or Perish, sciencedirect.com, academia.edu, proquest.com, dimensions.ai, and scholar.google.com. Relevant keywords such as "sustainability and forex," "machine learning and forex," "artificial intelligence and forex," "forex trading robots," "risk management and forex," and "portfolio and forex" were utilized to ensure comprehensive coverage of the topic.
2. Initial filtering: An initial filtration process was conducted to remove duplicate and irrelevant references from the collected data, ensuring a streamlined and pertinent dataset.
3. Quality assessment: The quality of publications was assessed using scimagojr.com to evaluate journal impact factors. This step ensured that only high-quality and reputable sources were included in the analysis, resulting in 56 suitable references.
4. Meta-analysis: A meta-analysis was performed to tailor the collected references to the specific topic requirements. This analysis focused on synthesizing and analyzing references related to AI and sustainability in forex trading.
5. Refinement and categorization: The refined selection of references was categorized based on their relevance to the identified topics. Further refinement was performed based on publication year and quartile rankings to ensure a robust and organized dataset.
6. Data representation: The distribution of references related to AI and sustainability was presented across different years and quartiles. Tables and diagrams were generated to visually represent the data, facilitating better understanding and interpretation. Additionally, rich pictures were used to visually map the complex interactions within AI-driven sustainability in forex trading. Causal loop diagram (CLD) is employed to clarify the feedback mechanisms linking AI technologies, market dynamics, and sustainability outcomes, enhancing the comprehensive analysis of AI's impact on forex trading practices.

Figure 1.
Sequential Flow of Methodology for Literature Analysis in Forex Trading

This figure outlines a step-by-step process for analyzing literature in forex trading. It includes data collection, filtering, quality assessment, meta-analysis, refinement, and representation of findings.



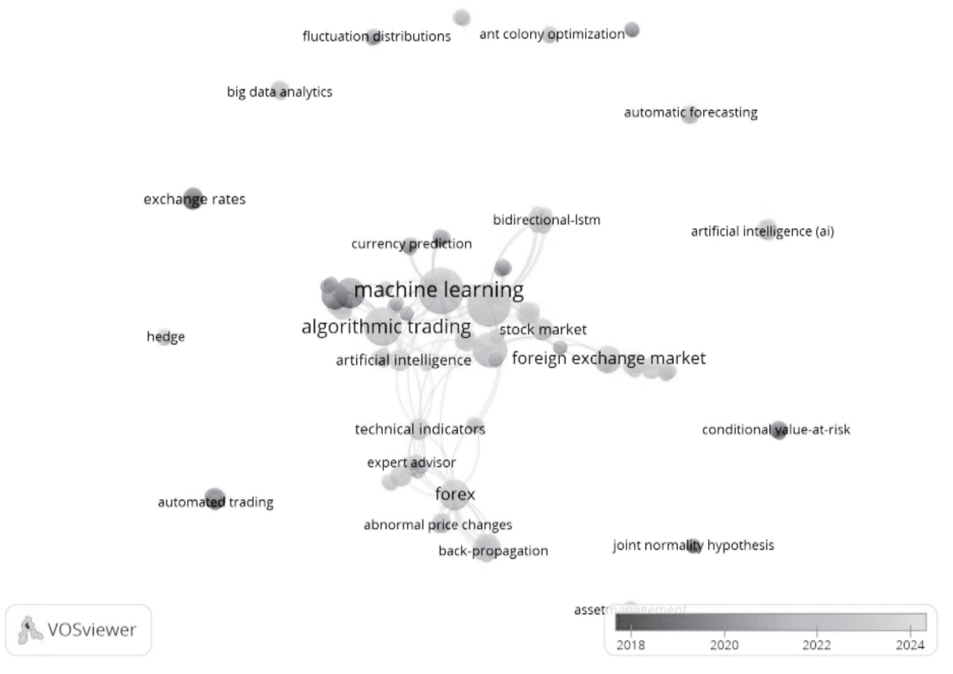
III. MAIN FINDINGS

A. Visualization of Machine Learning in Forex Robot Trading Using Overlay Diagrams

In this preliminary study, VoSViewer was utilized to generate overlay diagrams, an essential component of the bibliometric analysis. Bibliometric analysis involves the quantitative assessment of research publications and is widely used to map the scientific landscape, identify research trends, and analyze the impact of publications. VoSViewer, a tool specifically designed for constructing and visualizing bibliometric networks, facilitated the creation of overlay diagrams that represent the temporal evolution of research themes and the interrelationships between various studies (Wong, 2018). By using overlay visualization, the study was able to highlight the progression of research topics over time and identify key areas of focus within the fields of AI and sustainability in forex trading. This approach provided valuable insights into the development and trajectory of scholarly work, contributing to a deeper understanding of the research landscape.

Figure 2.
VOSviewer Overlay Results Based on Keywords: Reinforcement Learning, Fuzzy Inference System, forex trading, robot trading, Machine Learning

This figure illustrates a VOSviewer overlay map highlighting keyword relationships in forex trading research, such as "machine learning," "algorithmic trading," and "foreign exchange market." The color gradient represents the publication timeline, with keywords in green and yellow indicating more recent focus areas.



We present the application of overlay diagrams to visualize the research landscape of machine learning in forex robot trading (see Figure 2). The overlay diagrams generated by VoSViewer illustrate the dynamic and evolving nature of this research field. Through these diagrams, we can observe the temporal development and key interconnections of various studies, shedding light on how machine learning techniques have been applied and advanced in the context of forex trading robots. This visualization not only maps out the historical progression but also highlights emerging trends and potential future directions for research, offering a comprehensive overview for scholars and practitioners in the field.

B. Sustainability and Forex Trading Robots

In facing current global challenges such as environmental impact and sustainability, research in forex trading increasingly emphasizes the importance of implementing responsible artificial intelligence. A study by (Ullah *et al.*, 2021) highlights how crucial it is to use responsible algorithms in transactions, emphasizing transparency, fairness, and ethics in decision-making. They also show that the application of Socially Responsible Investment (SRI) principles in the context of forex trading robots can help reduce market risks caused by unethical trading behavior. Additionally, research by (Karagiannopoulou *et al.*, 2022) indicates that external factors such as consumer confidence indexes and exchange rates can significantly impact the performance and environmental impact of automated trading systems. This underscores the importance of considering economic and environmental factors in the development of forex trading robots.

Moreover, sustainability also becomes a focus in the technical aspects of forex trading robot development. Research by (Georgiou *et al.*, 2022) reveals significant differences in energy consumption and execution time performance between deep learning frameworks such as PyTorch and TensorFlow. This highlights the need to use more energy-efficient AI frameworks to reduce the carbon footprint of automated trading systems. The concept of green AI is also introduced as a rapidly growing strategy to mitigate the environmental impact of AI systems (Verdecchia *et al.*, 2023). To achieve this goal, approaches such as model optimization, efficient energy usage, and data-centric approaches are crucial. However, research also warns about the risks involved in the development of artificial intelligence technology. The concept of red AI, which highlights the high energy costs and carbon footprint in AI system development (Schwartz *et al.*, 2019), emphasizes the need to avoid inefficient approaches and focus on environmentally friendly practices.

From a technical standpoint, research on the use of various Machine Learning (ML) techniques and algorithms in the development of forex trading robots provides insights into the potential development of systems that are more adaptive and responsive to market information (Almeida and Araújo, 2019) (Chen *et al.*, 2019) (Gao *et al.*, 2021). Additionally, research explores trading strategies that use a combination of various technical analysis techniques and machine learning to improve the performance of forex trading (Sadat and Fazel Zarandi, 2022) (Trivedi and Chauhan, 2022) (Zhang *et al.*, 2023). Approaches that combine deep learning techniques with dynamic time warping are also proposed to enhance the performance of forex trading systems (Zhang *et al.*, 2023).

Finally, the development of hybrid models that leverage Reinforcement Learning (RL) techniques is also highlighted in recent research (Zhao *et al.*, 2023). These models can learn from trading experiences and enhance the performance of forex trading adaptively, providing hope for the development of more responsive and effective systems in addressing complex global market challenges.

C. Exploring Forex Trading Robots and AI Methods within the SARSA-FIS Framework

Robot trading utilizes various AI algorithms, including ML methods such as RL, to enhance risk management and profitability. (Vezeris *et al.*, 2018) highlight the effectiveness of ML methods in improving trading performance. For instance, ML techniques, including Deep Learning (DL) models such as Convolutional Neural Networks (CNN), Deep Neural Networks (DNN), Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), have been extensively employed in financial market analysis, as noted by (Hu *et al.*, 2021). These methods are instrumental in predicting price movements in both stock and forex markets. However, while DL methods are capable of processing vast and diverse market data rapidly, they often require substantial amounts of data and computational resources. Additionally, DL models are considered black boxes, making them challenging to interpret, as emphasized by (Chihab *et al.*, 2019). Conversely, RL methods, widely recognized for their potential in improving algorithm performance, particularly in prediction accuracy and transaction profitability, still require further research, as highlighted by (Khushi and Meng, 2019) and (Li *et al.*, 2020). The figures provided illustrate the significant attention ML methods, especially in algorithmic trading for the forex market, have garnered. From the timelines analysis presented in Figure 3 and Figure 4, it is evident that opportunities for research in ML methods, particularly in hybrid systems, remain open.

The timeline depicted in Figure 3 provides a comprehensive overview of the evolving research landscape concerning sustainability and artificial intelligence (AI) in the domain of forex trading robots from 2018 to 2024. This period witnessed significant scholarly contributions, marking pivotal advancements in integrating sustainable practices with cutting-edge AI technologies in financial trading systems. In 2018, the foundational work by authors such as (Pendharkar and Cusatis, 2018), (Jubert de Almeida *et al.*, 2018) set the stage for subsequent research endeavors. Their studies explored the AI-driven trading mechanisms. As the field progressed into 2019 and 2023, researchers like (Schwartz *et al.*, 2019), (Ullah *et al.*, 2021), (Georgiou *et al.*, 2022), (Verdecchia *et al.*, 2023) expanded on these concepts, delving deeper into the application of AI algorithms to enhance the sustainability and efficiency of forex trading robots. The years 2019 and 2022 saw a marked increase in research activity. This period was characterized by a diversification of research themes, including risk management, predictive analytics, and the optimization of trading strategies using AI. The collaborative efforts of multidisciplinary teams enriched the discourse, fostering innovative solutions that balanced profitability with sustainable trading practices.

From 2022 onwards, the field experienced a surge in technological advancements and theoretical frameworks, as highlighted by the works of authors like (Georgiou *et al.*, 2022) and (Verdecchia *et al.*, 2023). These studies emphasized the integration of AI with Environmental, Social, and Governance (ESG) criteria, aiming to develop forex trading robots that not only excel in performance but also adhere to sustainable investment principles. The timeline showcases a robust body of research that underscores the importance of sustainability in the rapidly evolving AI landscape. The collective efforts of these scholars have paved the way for the development of intelligent, sustainable trading systems that are poised to revolutionize the forex market. This timeline serves as a testament to the dynamic and interdisciplinary nature of research in this field, reflecting the ongoing commitment of the academic community to foster sustainable and technologically advanced solutions in forex trading.

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Figure 3.
Timeline of Research on Sustainability and Artificial Intelligence for Forex Trading Robots

This figure presents a timeline illustrating the progression of research on sustainability and artificial intelligence in forex trading robots from 2018 to 2024. It highlights key authors and their contributions, showing how the field has evolved over time with increasing focus on advanced technologies and sustainable practices.

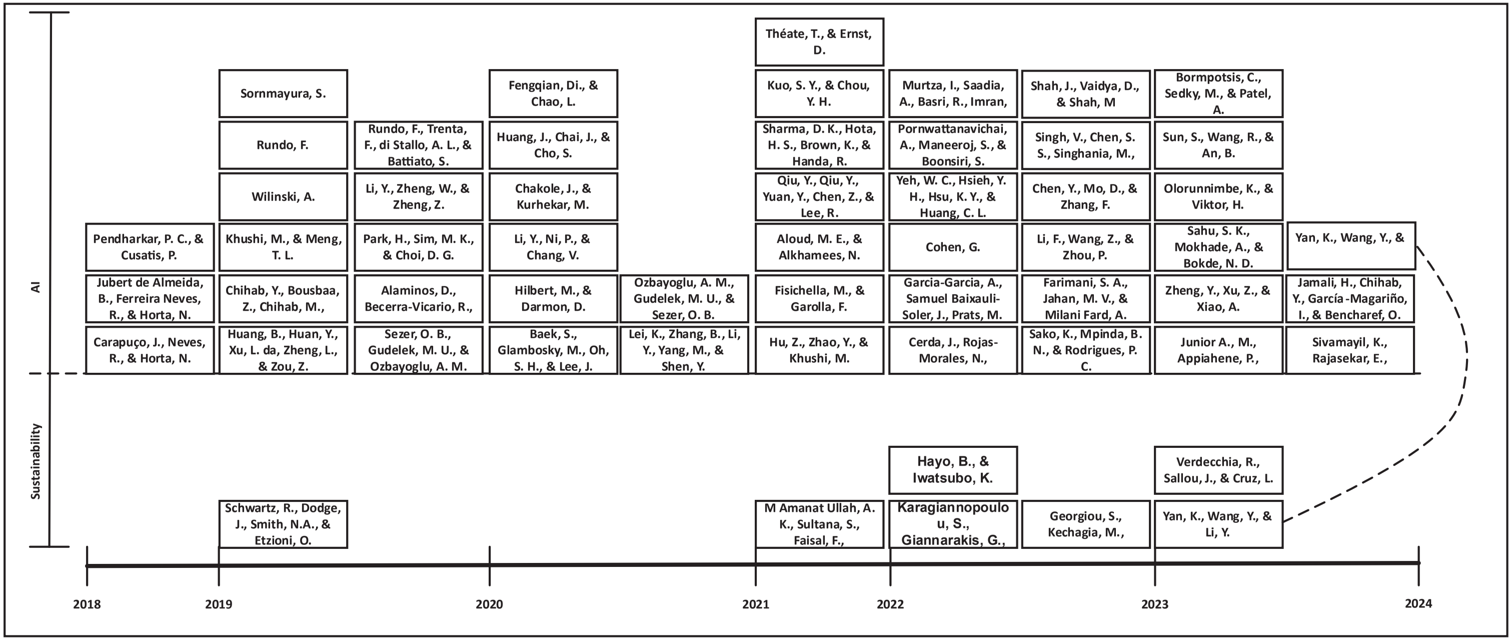


Figure 4.
Timeline of Research on AI Methods in Forex Trading

This figure presents a chronological mapping of research contributions in the field of artificial intelligence applied to forex trading. It illustrates key studies, their interconnections, and the progression of methodologies over time. Each box represents a significant research paper or study, organized along a timeline. The links between studies indicate methodological influences, highlighting the development and interrelated nature of AI research in this domain.

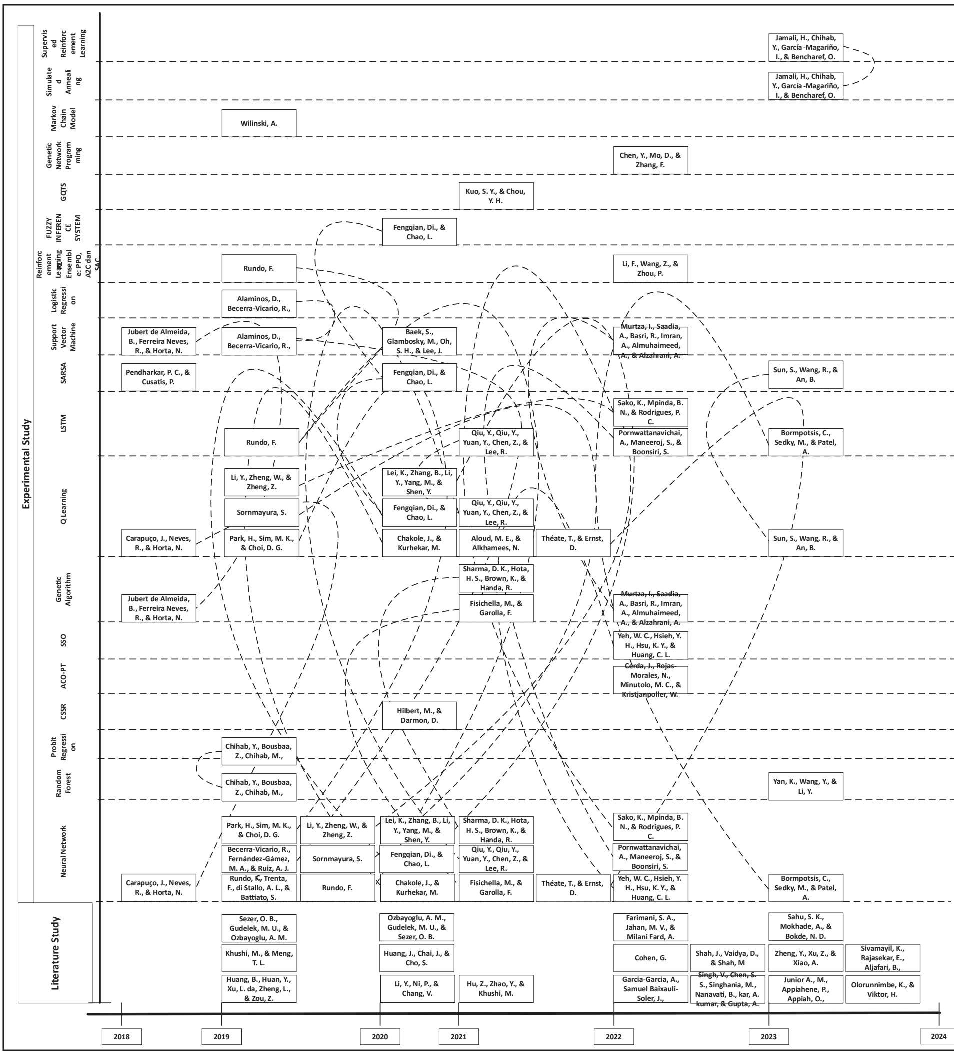


Figure 4 provides a detailed overview of the research landscape concerning various AI methods applied in forex trading robots from 2018 to 2024. This period is marked by significant scholarly contributions that explore and enhance AI-driven trading systems through diverse methodologies. In 2018, the work by authors such as (Carapuço *et al.*, 2018) studies on the use of clustering techniques in forex trading. Simultaneously, literature reviews by authors like (Huang *et al.*, 2019). set the stage for subsequent research endeavors. These contributions provided an example for integrating AI methodologies in trading systems. As the field progressed into 2019 and 2020, researchers like (Rundo, 2019), (Alaminos *et al.*, 2019), (Fengqian and Chao, 2020), (Chakole and Kurhekar, 2020) expanded on these concepts, exploring experimental studies that employed various AI techniques such as reinforcement learning and deep learning.

The years 2021 and 2022 saw a marked increase in research activity, with significant contributions from (Fisichella and Garolla, 2021), (Sharma *et al.*, 2021), (Yeh *et al.*, 2022a), (Cerda *et al.*, 2022). This period was characterized by the diversification of research themes, including hybrid models and advanced predictive analytics. The interconnectedness of different methodologies is highlighted by the dotted lines connecting various authors, indicating the multi-method approaches prevalent during this time. From 2023 onwards, the field experienced a surge in technological advancements and theoretical frameworks, as highlighted by the works of (Sun *et al.*, 2023), (Bormpotsis *et al.*, 2023), (Yan *et al.*, 2023). These studies emphasized integrating AI with comprehensive market analysis and risk management strategies, aiming to develop robust and adaptive forex trading systems. The collective efforts of these scholars have paved the way for developing intelligent trading systems that leverage multiple AI techniques for enhanced performance and sustainability. This timeline serves as a testament to the dynamic and interdisciplinary nature of research in this field, reflecting the ongoing commitment of the academic community to foster advanced and effective AI-driven solutions in forex trading.

Table 2.
Summary of AI Methods Utilized in Trading Robots

This table provides a summary of the various Artificial Intelligence (AI) methods utilized in trading robots, along with the corresponding references. The references indicate the studies that have implemented these methods in the development and application of trading robots.

AI Methods	References
CNN, DNN	(Hu *et al.*, 2021), (Zheng *et al.*, 2023)
DRL	(Zheng *et al.*, 2023), (Khushi and Meng, 2019), (Li *et al.*, 2020), (Sahu *et al.*, 2023), (Chakole and Kurhekar, 2020), (Olorunnimbe and Viktor, 2023), (Sahu *et al.*, 2023)
Q-learning	(Khushi and Meng, 2019), (Li *et al.*, 2020)
AI, Fuzzy Systems, NN	(Cohen, 2022), (Fengqian and Chao, 2020)
DL	(Cohen, 2022), (Sahu *et al.*, 2023), (Olorunnimbe and Viktor, 2023)
ML	(Cohen, 2022), (Sahu *et al.*, 2023)
Long Short-Term Memory (LSTM)	(Yeh *et al.*, 2022b), (Cohen, 2022)
Simplified Swarm Optimization (SSO)	(Yeh *et al.*, 2022b)
Genetic Algorithm, Support Vector, Machine (SVM), Random Forest, AdaBoost, XGBoost	(Fisichella and Garolla, 2021)
Generalised Behaviour Learning Method	(Khushi and Meng, 2019)
DQRL	(Li *et al.*, 2020), (Chakole and Kurhekar, 2020)
SARSA	(Pendharkar and Cusatis, 2018), (Fengqian and Chao, 2020), (Sun *et al.*, 2023)

In the realm of finance and stock transactions, various AI methods (see Table 2) have been employed, providing deep insights into recent advancements in the field. One such method is Adaptive Reinforcement Learning (ARL), applied in automated trading systems within the forex market, showcasing ARL's adaptability in highly dynamic market environments. The utilization of CNN and DNN in forex and stock price predictions (Hu *et al.*, 2021) (Zheng *et al.*, 2023) reflects the widespread adoption of DL in the economic domain.

Deep Reinforcement Learning (DRL) has also seen extensive use in economics and finance (Khushi and Meng, 2019) (Li *et al.*, 2020) (Olorunnimbe and Viktor, 2023), addressing applications ranging from stock price prediction to transaction strategy development and systematic surveys of its real-world applications and backtesting in stock markets. Q-learning (Khushi and Meng, 2019) (Li *et al.*, 2020) is also leveraged in RL to comprehend and optimize stock trading strategies.

The combination of AI, FIS, and NN, as emphasized by (Cohen, 2022), presents a holistic approach in algorithmic trading and financial prediction. The implementation of DL, ML, and LSTM is also evident in the literature (Cohen, 2022) (Yeh *et al.*, 2022b). Optimization methods such as Simplified Swarm Optimization (SSO) have proven relevant in grid trading models (Yeh *et al.*, 2022b), showcasing how optimization applications can enhance transaction strategy effectiveness in finance. Other AI methods such as Genetic Algorithm, Support Vector Machine (SVM), and Random Forest, as discussed by (Fisichella and Garolla, 2021), highlight efforts to enhance forex data technical analysis methods for future price movement predictions. Generalized Behaviour Learning methods, as elucidated by (Khushi and Meng, 2019), are also applied in RL contexts to understand market dynamics in financial markets. The implementation of DQLR, as outlined in (Li *et al.*, 2020) and (Chakole and Kurhekar, 2020), demonstrates the effectiveness of Q-Learning approaches in developing stock trading strategies, particularly in trend-following endeavors.

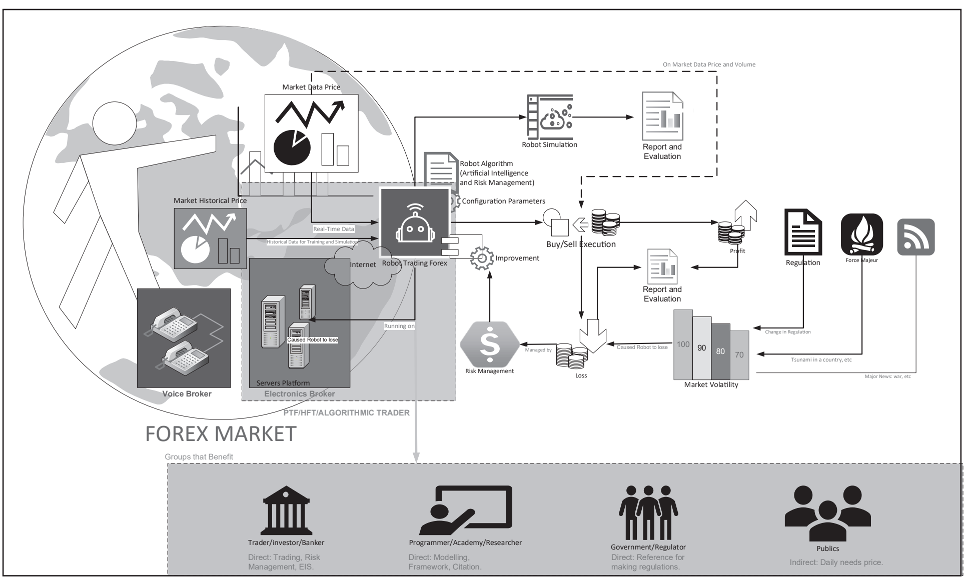
The integration of ML techniques, particularly RL algorithms like SARSA, and Fuzzy Inference System (FIS) in forex trading presents a transformative potential in reshaping trading practices. As highlighted by (Hilbert and Darmon, 2020), SARSA offers a straightforward yet powerful method for developing intelligent and adaptive trading strategies, while FIS addresses market uncertainty and aids in decision-making processes, as noted by (Chihab *et al.*, 2019). This hybridization of SARSA and FIS represents an innovative approach to enhancing trading performance, leveraging the strengths of both methods. According to (Pendharkar and Cusatis, 2018), SARSA's capability to generate intelligent strategies complements FIS's ability to handle uncertainty, resulting in more accurate decision-making processes. By combining SARSA as input for FIS, the hybrid system achieves high accuracy in decision-making amidst dynamic market conditions, as emphasized by (Sun *et al.*, 2023). Furthermore, the study explores the potential of combining SARSA-FIS with Triangular Hedging (TH) methods to manage risks effectively and adapt to market dynamics, as suggested by (Cerda *et al.*, 2022). In essence, the findings underscore the importance of exploring hybrid approaches in forex trading, offering insights into the development of intelligent trading algorithms and strategies that can effectively navigate the complexities of dynamic market environments.

D. Visualizing the Concept: A Rich Picture of Forex Trading Robot Ideas

The journey towards conceptualizing a forex trading robot involves a complex interplay of various factors and dynamics, which can be vividly captured in a rich picture (refer to Figure 5). This rich picture serves as a holistic representation (Bell *et al.*, 2019), allowing us to delve into the cognitive processes and reflective stages (Bell and Morse, 2013) that culminate in the formulation of ideas for developing effective and sustainable trading robots. At the heart of the rich picture lie the intricate connections between technological advancements, market dynamics, and human decision-making. It portrays the fusion of cutting-edge AI technologies with the nuanced understanding of market trends and patterns. These technologies, including ML algorithms and DRL, are depicted as the engine driving the evolution of trading strategies within the forex market landscape.

Figure 5.
Unveiling the Landscape: A Rich Picture of Forex Trading Robot Ideation

This figure provides a comprehensive visualization of the conceptual landscape behind forex trading robot ideation. It integrates key components, including market data analysis, algorithm design, decision-making processes, and user involvement, highlighting the interconnected elements that shape the development and operation of forex trading robots.



Surrounding this technological core are layers of contextual elements and influencing factors. Economic indicators, geopolitical events, and regulatory frameworks form a backdrop against which trading decisions are made. The rich picture captures the flux of market sentiment, reflected in the ebb and flow of price movements depicted graphically. Furthermore, the human dimension is also prominently featured in the rich picture. Traders' expertise, emotions, and risk appetites interplay with algorithmic trading strategies, shaping the overall trading ecosystem. The iterative process of idea generation, experimentation, and refinement is illustrated, highlighting the continuous quest for innovation and optimization in the realm of forex trading robots.

The diagram presents a comprehensive overview of the positioning and influence of forex trading robots within the forex market, detailing the factors impacting their operation and the resulting effects on market dynamics. At the core of the illustration, the forex trading robot is depicted as a pivotal component, interfacing with various market elements such as market indicators, data analytics, and algorithmic trading strategies. These robots utilize advanced algorithms to analyze market trends, execute trades, and manage portfolios, thereby contributing to market liquidity and efficiency. The left section of the diagram highlights the data sources feeding into the trading robots, including real-time market data, historical price data, and financial news. This influx of information enables the robots to make informed decisions, optimizing trading strategies in response to market fluctuations. The integration of cloud computing is also depicted, signifying the importance of robust computational resources in processing large dataset, and executing complex algorithms at high speeds.

Moving to the right side of the diagram, the impacts of forex trading robots are outlined, showcasing their influence on market performance metrics such as trading volume, volatility, and price stability. The diagram also addresses regulatory considerations, emphasizing the need for compliance with financial regulations and the role of oversight bodies in ensuring fair trading practices. The bottom section illustrates the broader ecosystem involving various stakeholders, including financial institutions, technology providers, and traders. Financial institutions benefit from the enhanced trading capabilities provided by these robots, while technology providers continue to innovate, developing more sophisticated algorithms and trading platforms. Traders, on the other hand, experience a shift in their roles, as they increasingly rely on automated systems to manage their investments. Overall, the rich picture encapsulates the multifaceted nature of forex trading robots, highlighting their central role in the forex market, the technological and regulatory frameworks supporting their operation, and their far-reaching impacts on market dynamics and stakeholder interactions. This visual representation underscores the complexity and interconnectivity of modern forex trading, driven by technological advancements and evolving market practices.

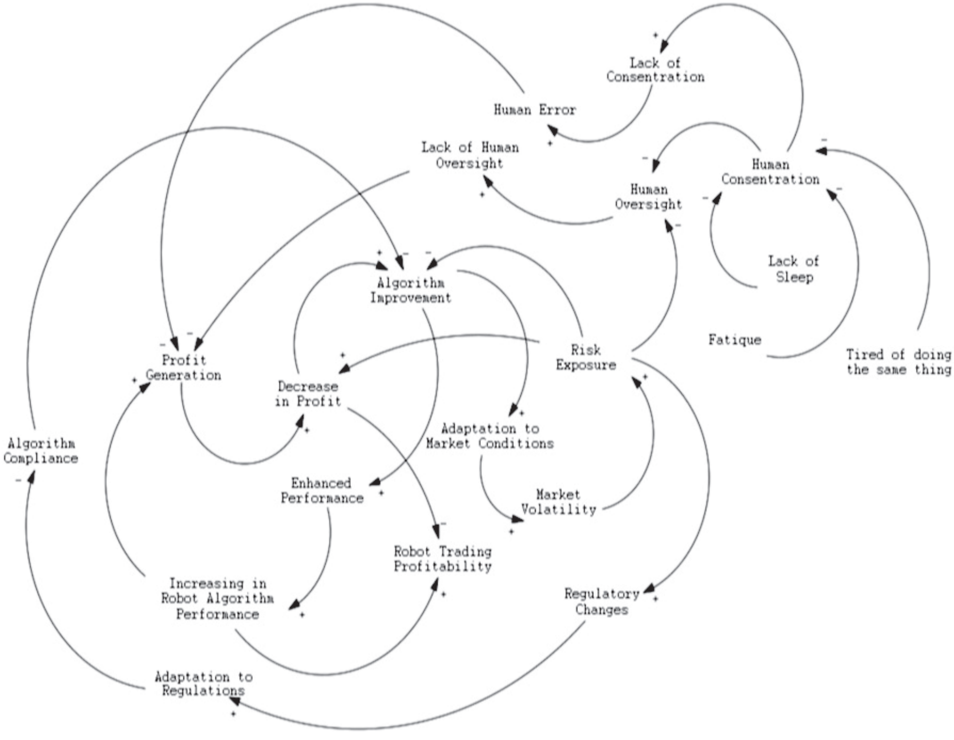
E. Mapping the Dynamics: CLD of Forex Trading Robots

The CLD offers a nuanced understanding of the intricate web of factors influencing the dynamics of the system (Dhirasasna and Sahin, 2019). In the forex trading system, it specifically focuses on the interplay between automated trading algorithms and human interventions (refer to Figure 6). At its core, the CLD encapsulates the complex relationships between various elements within the forex trading ecosystem. It highlights the presence of feedback loops, both positive and negative, which play a pivotal role in shaping the behavior of the system. Positive feedback loops amplify trends and market movements, while negative feedback loops act as stabilizing forces, mitigating excessive fluctuations. Moreover, the CLD illustrates the influence of external factors on the forex market, such as economic indicators, geopolitical events, and regulatory changes. These external influences serve as catalysts that can trigger shifts in market sentiment and trading patterns. Central to the CLD is the interaction between automated trading algorithms and human interventions. Automated algorithms, driven by complex mathematical models and AI technologies, execute trades based on predefined parameters and market signals. However, human interventions, such as manual overrides, strategic adjustments, and emotional responses, introduce a layer of unpredictability and adaptability into the system.

Furthermore, the CLD elucidates the role of balancers, which act as mechanisms to maintain equilibrium within the system. These balancers may include risk management protocols, market regulations, and feedback mechanisms designed to ensure stability and prevent market manipulation. In essence, the CLD provides a comprehensive visual representation of the dynamic interplay between automated trading algorithms, market conditions, external influences, user interventions, and human behavior within the forex trading landscape. It serves as a valuable tool for understanding the complexity of forex transactions and the challenges inherent in balancing automation with human decision-making.

Figure 6.
Unraveling Complexity: CLD of Forex Trading Robots

This figure presents a CLD highlighting the complex interrelationships among various factors influencing forex trading robots. It illustrates feedback loops, such as how human errors, market volatility, algorithm compliance, and regulatory changes interact to impact trading performance, risk exposure, and profitability.



The CLD presented in Figure 6 provides a comprehensive visualization of the various factors influencing the performance of forex trading robots and their subsequent impact on profitability. This diagram elucidates the intricate dynamics between human oversight, algorithmic improvements, market conditions, and regulatory changes, all of which contribute to the overall effectiveness of forex trading robots. At the core of the diagram, profit generation is depicted as a critical outcome influenced by multiple interconnected factors. Algorithm improvement plays a pivotal role, enhancing the performance of trading robots and thereby increasing profitability. This improvement is driven by continuous adaptation to market conditions and compliance with regulatory changes. As robots adapt to market volatility and shifting regulations, their algorithms become more sophisticated, leading to better trading outcomes.

However, the diagram also highlights potential challenges. Human error and lack of oversight can negatively impact robot performance, leading to decreased profits. Factors such as lack of concentration, fatigue, and insufficient human oversight contribute to these errors, illustrating the importance of maintaining a balanced human-robot interaction in trading environments. Risk exposure is another crucial element depicted in the diagram. Increased risk exposure, driven by market volatility and regulatory changes, necessitates ongoing algorithmic adaptation to mitigate potential losses. The interplay between risk exposure and algorithm improvement underscores the dynamic nature of forex trading, where continuous learning and adjustment are essential for sustained success. The diagram portrays the cyclical relationship between profit generation and algorithm performance. Enhanced performance leads to increased profitability, which in turn fuels further algorithmic improvements and compliance with evolving regulations. This positive feedback loop emphasizes the iterative nature of developing and deploying effective forex trading robots. The CLD offers a detailed representation of the multifaceted factors influencing forex trading robot performance. It highlights the importance of algorithmic sophistication, human oversight, and adaptive strategies in navigating the complexities of the forex market. By visualizing these dynamics, the diagram provides valuable insights into the mechanisms driving the success and challenges of forex trading robots, underscoring the need for continuous innovation and careful management in this domain.

IV. CONCLUSIONS AND IMPLICATIONS

The exploration of AI-driven forex trading robots through advanced bibliometric and visualization techniques has provided profound insights into the evolving landscape of ML applications within this domain. The use of VoSViewer and the CLD has illuminated the temporal progression, key trends, and intricate dynamics shaping the effectiveness and sustainability of forex trading systems. The bibliometric analysis reveals a significant evolution in the integration of advanced machine learning techniques—such as RL, FIS, and DL—into forex trading robots from 2018 to 2024. This progression highlights a growing sophistication in trading strategies, driven by technological innovation and improved adaptability to market conditions. Additionally, the research underscores the critical need for incorporating sustainability principles into the development of trading robots. The emphasis on responsible AI practices, including transparency, fairness, and ethical decision-making, aligns with the broader movement toward SRI and environmental considerations. The findings also stress the importance of adopting energy-efficient AI technologies and green AI practices to mitigate the carbon footprint of trading systems. The study further demonstrates the transformative potential of hybrid models, particularly the SARSA-FIS framework, in enhancing the adaptability and accuracy of trading systems. The effective management of uncertainties and optimization of decision-making processes in dynamic market environments are achieved through the integration of RL algorithms with FIS. Moreover, exploring the combination of SARSA-FIS with TH methods suggests promising future research directions in risk management. The CLD highlights the complex interplay between algorithmic improvement, market dynamics, and human oversight, emphasizing the cyclical nature of algorithm enhancement and profit generation, the impact of external factors, and the need for balanced human-robot interaction to mitigate risks and ensure robust trading strategies.

Considering these findings, the study provides a roadmap for future research in AI-driven forex trading robots, advocating for continued exploration of hybrid models and RL techniques. Researchers and practitioners are encouraged to delve deeper into integrating advanced AI methods with sustainable practices to further enhance trading performance and ethical standards. Financial institutions and technology developers should prioritize responsible AI principles and green AI technologies to foster a more ethical and sustainable trading environment. Additionally, policymakers need to consider the implications of AI-driven trading systems on market stability and ethical behavior, working towards guidelines that promote responsible and sustainable practices. Emphasizing the importance of manual intervention and strategic adjustments alongside algorithmic decision-making can enhance human-robot collaboration and risk management. Finally, future studies should investigate new methodologies, such as integrating dynamic time warping with DL and combining SARSA-FIS with TH, to refine trading strategies and address the complexities of global financial markets. Overall, these conclusions and implications offer a comprehensive framework for advancing AI-driven forex trading robots, integrating cutting-edge technologies with sustainable and responsible practices to drive innovation and enhance trading performance in an ethically and environmentally conscious manner.

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