

# Integration of Robo-Advisors and Environmental, Social and Governance Investing

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**Abstract.** With fast development and widespread use of Fin-tech currently, as one important part of it, Robo-advisors, which feature in driving asset allocation and portfolio management by algorithm, are applied in practice. At the same time, the symbol of the concept of responsible investment, Environmental, Social and Governance (ESG) investing, has become a mature investing field from a newborn concept. An integration of an investing tool and an investing field has great potential. This paper aims to construct a theoretical integration framework of robo-advisors and ESG investing from four dimensions: data integration, investor preference identification, algorithmic mechanism design, and compliance and transparency, by reviewing existing literature. This integrated model not only enhances the accessibility, personalization, and sustainability of investments, but also faces challenges such as insufficient data standardization, limited algorithm interpretability, and weak market adaptability. In the last, this paper gives a conclusion that the future focus should be on the promotion of the establishment of unified ESG data standards, finding optimization algorithms of intelligent methods for investor preference identification, and the development of explainable artificial intelligence (XAI) to foster the development of transparent, compliant, and efficient ESG-oriented robo-advisory systems.

**Keywords:** Robo-advisors; ESG investing; fin-tech; sustainable finance; sustainable investment.

## 1. Introduction

In recent years, the rapid development of financial technology (FinTech) has reshaped the landscape of investment advisory services. Robo-advisors, defined as algorithm-driven automated platforms, have become a prominent solution for providing low-cost, personalized, and data-driven portfolio management [1,2]. Since their emergence in the aftermath of the 2008 financial crisis, platforms such as Betterment and Wealthfront have demonstrated how digital advisory can reduce barriers to entry and offer reliable financial guidance to retail investors. By automating tasks such as portfolio rebalancing, tax-loss harvesting, and risk assessment, robo-advisors have disrupted traditional wealth management and opened new opportunities for financial inclusion [3].

Meanwhile, environmental, social, and governance (ESG) investing has gained remarkable traction, reflecting broader global concerns about climate change, social inequality, and corporate accountability. A growing body of literature and industry practice has confirmed that ESG integration is no longer a niche strategy but an essential part of mainstream investment [4,5]. Global ESG assets under management surpassed USD 35 trillion in 2020 and are projected to reach USD 50 trillion by 2025, representing more than one-third of total assets worldwide [6]. Asset managers such as BlackRock and Vanguard have already embedded ESG factors into core investment processes, indicating a structural transformation in capital allocation toward sustainable goals [7].

The integration of ESG principles into Robo-advisors' systems represents a unique intersection of quantitative algorithmic design and qualitative value-driven judgment. On the one hand, Robo-advisors rely on large-scale data processing, machine learning, and optimization techniques to construct efficient portfolios. On the other hand, ESG considerations emphasize values, preferences, and long-term societal impact. Combining the two, therefore, not only extends the functionality of Robo-advisors platforms but also democratizes access to responsible investing for retail investors who may otherwise lack the expertise or resources to navigate ESG products [8,9]. In practice, platforms such as Betterment and Wealthfront have introduced socially responsible investment

options, and recent experiments show that retail investors are increasingly willing to adopt ESG-oriented Robo-advisors if transparency and alignment with personal values are ensured [10].

From a theoretical standpoint, embedding ESG considerations into robo-advisory services bridges multiple disciplines, including behavioral finance, machine learning, and sustainable finance [5]. This integration raises several important research questions: how to address the divergence of ESG ratings across providers, how to capture investors' heterogeneous sustainability preferences, how to design algorithms that balance risk-adjusted returns with ESG objectives, and how to ensure compliance with evolving regulatory frameworks. Recent studies suggest that explainable artificial intelligence and standardized ESG data disclosure will be crucial for enhancing trust and comparability across Robo-advisors platforms [11,12].

Compared with existing literature that often treats Robo-advisors and ESG investing as separate domains, this paper provides a structured overview of their convergence. By synthesizing current research and practice, it identifies underexplored intersections, highlights key challenges such as data inconsistency and algorithmic opacity, and proposes directions for building transparent, ethical, and personalized ESG-Robo-advisors systems. In doing so, this review aims to contribute to the ongoing discourse on how FinTech innovation can support global sustainable finance and foster inclusive, value-aligned investment ecosystems.

## **2. Theoretical Analysis**

### **2.1. Robo-advisors**

Robo-advisors are one of the most important applications of Fin-tech in wealth management field, whose core is to use algorithms and artificial intelligence to realize automated asset allocation and portfolio management. At an early stage, it mainly relied on the model based on the Modern Portfolio Theory(MPT), and tried to offer low-cost investment services [13]. In recent years, with the advancement of big data, machine learning, and natural language processing (NLP) technologies and so on, Robo-advisors have gradually evolved into comprehensive platforms capable of identifying investors' personalized needs and dynamically adjusting asset allocations [14]. For instance, the application of deep learning techniques in market forecasting and portfolio optimization has significantly improved the risk–return performance of investment portfolios [12,15].

The distinctive advantages of robo-advisors lie in their inclusiveness and scalability. Through automated processes, they can deliver professional investment services that were once accessible only to high-net-worth clients, thereby expanding financial services to a broader range of retail investors [16]. Moreover, empirical studies indicate that by leveraging real-time data analysis and personalized recommendations, robo-advisors can effectively enhance investor satisfaction and strengthen investment stickiness [9]. Incorporating methods from behavioral finance, robo-advisors are also employed to detect investors' latent biases and degrees of risk aversion, enabling the design of more rational and tailored investment strategies [10,17].

Every field encounters development barriers, and robo-advisory is no exception. Recommendation logic which is lacking transparency makes it difficult for investors to understand, thereby destroying the foundation of trust. Moreover, cross-country differences in regulatory regimes result in pronounced disparities in compliance and adoption of robo-advisors [3]. Issues related to data privacy protection and platform security are equally pressing . Recent studies suggest that enhancing algorithm interpretability and strengthening compliance frameworks can help strike a balance between innovation and risk, thus fostering the long-term development of robo-advisory services [11].

### **2.2. ESG Investing**

Environmental, Social, and Governance investment has emerged as a hot topic in global capital markets and has recently become increasingly accessible and is gaining interest among consumers. For corporations, extensive research demonstrates that strong ESG performance not only enhances reputation and long-term competitiveness [13], but also significantly reduces capital costs and risk

exposure [4]. At the international level, initiatives such as the Principles for Responsible Investment (PRI) have provided an institutional foundation for ESG investing [5], while the scale of global sustainable investment has maintained rapid growth over the past decade [6]. In practice, the focus of ESG application has shifted from “whether it is effective” to “how to create value.” Empirical studies indicate that ESG factors are significantly associated with the risk-adjusted returns of investment portfolios, serving as a stabilizer particularly under high market uncertainty [9]. At the same time, shifting preferences among younger and institutional investors have further fueled the expansion of ESG-related investment tools [7]. For instance, the study by Novak and Weber draws on fund inflow data and market performance indicators across multiple European countries, applying empirical modeling to examine investor behavior, and finds that capital inflows into sustainable funds depend not only on financial performance but are also influenced by Environmental, Social, and Governance (ESG) ratings [14].

The promotion of technology pushes the development of ESG investing. Machine Learning has been widely applied in corporate ESG performance forecast, which is able to improve rating accuracy and the portfolio stability effectively [15]. Also, Lee, J., & Kim, S. constructed a natural language processing risk scoring model to quantify textual information into corporate ESG risk indicators. They then compared this model with traditional ESG ratings and market reactions (such as stock price fluctuations) to examine its effectiveness and predictive power. Their research suggests that natural language processing applied to the analysis of unstructured data, such as news, social media, and annual reports, can help investors identify potential ESG risks and opportunities for companies [16].

Despite the rapid development of ESG investing, there are still some challenges to be solved. The most important one is how to solve the problem of serious differences in rating standards, which leads to large differences in scores given to the same company by different rating agencies. Even Berg, F., Kölbel, J. F., & Rigobon, R.’s research has revealed what elements cause the divergence (scope, weight, and measurement), the problem is still there [17]. Secondly, some companies use ‘greenwashing’ to improve their sustainability scores without actually improving their sustainability performance. This is particularly prominent in emerging markets. For example, Mao, Wang, and Lin used Chinese listed companies as a sample and found that when ESG ratings diverge significantly, companies are more likely to use earnings management and other means to embellish their sustainability performance, reflecting typical greenwashing characteristics [18]. This is also why many studies in recent years, such as Organisation for Economic Co-operation and Development (OECD), have emphasized that establishing unified ESG disclosure standards and transparent regulatory mechanisms is the key to ensuring the long-term effectiveness of ESG investments [19].

### **3. Current Status of Integrated Research**

The integration of smart investment advisors and ESG investment has been a frontier in financial technology and sustainable finance in recent years. This cross-disciplinary field is not only a combination of technology and investment concepts, but also reflects the interaction between investor demand, market innovation and regulatory evolution. Initial exploration focused on trying to embed ESG-oriented factors into asset allocation models in order to meet investors' preferences for responsible investment [20]. Afterwards, researchers gradually shifted to model optimization and experimental testing, such as Dalne.G., who applied machine learning techniques to integrate ESG factors into portfolio optimization and found that ESG constraints did not significantly harm risk-adjusted returns [15].

#### **3.1. The Investor Level**

At the investor level, the younger generation and institutional investors have shown a higher demand for sustainable investment, and they tend to choose products that can balance financial returns and social value [5,7]. Empirical studies have found that investors' acceptance of ESG-oriented smart investment advisors has increased significantly, especially when the platform algorithms are

transparent and explainable [21]. This trend pushes innovation in smart investment advisors in identifying user preferences. The study of Faradynawati and Söderberg shows that by collecting users' risk preferences, investment horizons, and socio-demographic characteristics through questionnaires, and then combining them with users' actual behavior of choosing sustainable products, it is possible to effectively predict which customers are more inclined towards ESG/sustainable investments [10].

### **3.2. The Technical Level**

At the technical level, natural language processing technology can extract information from unstructured data such as news, announcements, and social media and dynamically update ESG scores, enabling smart investment advisors to quickly adjust their investment strategies during market fluctuations. This is considered the core advantage of integrated smart investment advisors. For example, Schimanski, T., Reding, A., et al. used large-scale pre-trained NLP models to analyze company reports and news texts in their research, and empirical evidence showed that it effectively improved the transparency and timeliness of ESG measurements [16].

### **3.3. Practice Level**

In practice, some financial institutions have launched ESG-themed Robo-advisors products for mass investors. These products not only provide financial returns but also display the performance of the portfolio in terms of environmental, social, and governance dimensions through a visual interface, thereby enhancing user stickiness and brand value [7].

## **4. Theoretical Integration Framework**

The integration of smart investment advisors and ESG is both a technical issue and a value issue. To truly integrate the two, four mutually supporting links are needed: data integration, preference identification, algorithmic mechanisms, and compliance and transparency. These four parts are not isolated, but rather interdependent.

### **4.1. Data Integration**

The real dilemma is that ESG data standards are not unified. Different rating agencies often give very different scores to the same company, making it difficult for investors to judge which one is better or worse [17]. Research suggests establishing a unified data interface to integrate corporate disclosures, third-party ratings, and media opinions into a multidimensional database [8]. For example, there are projects in the European market that attempt to package carbon emissions and supply chain transparency data into investment databases, allowing investment portfolios to more fully present corporate risk characteristics [14]. This approach can reduce the bias caused by a single score and make different assets comparable under the same standards.

### **4.2. Investor Preferences Identification**

Traditional investment advisors usually segment clients based on risk tolerance and investment horizon, but in the ESG context, this is far from enough. Investors may be very radical on climate issues but relatively conservative on corporate governance [9,10]. If the platform can capture these differences, the user experience will be significantly improved. Specific approaches include expanding questionnaire design, analyzing trading behavior, and even using NLP technology to extract keywords from user conversations or social media [16]. For example, when users frequently mention "carbon neutrality," the system will automatically increase the weight of green energy assets. This makes investment advice more personalized and more in line with investors' values.

### **4.3. Algorithmic Mechanism**

The algorithm is the core execution link of the framework. Research has proposed a multi-objective optimization method that incorporates risk-adjusted returns and ESG performance into the

objective function simultaneously [13]. Some models use deep learning methods, specifically Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) networks, in empowering robo-advisors to offer personalized investment recommendations and enhance decision-making processes for investors [12]. In addition, machine learning is also being tried to enable investment portfolios to self-update with market fluctuations and policy changes [15]. These explorations show that ESG is not a simple "additional indicator" but is written into the core of the algorithm logic.

#### **4.4. Compliance and Transparency**

Robo-advisors face the need to comply with relevant information disclosure requirements in most jurisdictions, which means that if they want to fully follow the regulations, the amount of information that can be analyzed will be reduced. In addition, the problem of how to build user trust faced by Robo-advisors will inevitably be solved by the transparent decision-making process of smart investment advisors. Therefore, the platform must clearly disclose the data source and processing flow, and introduce explainable artificial intelligence (XAI) to enable users to understand the recommendation logic [11]. In terms of ESG, what needs to be addressed urgently is the "greenwashing" behavior of companies in pursuit of better performance [18]. For example, the platform can mark the portfolio page as "This fund was included because its carbon emissions decreased by more than the industry average." This not only meets regulatory requirements but also enhances user trust. Organizations such as the OECD have proposed promoting unified disclosure standards to reduce cross-border regulatory friction [19].

### **5. Challenges**

While the integration of robo-advisors and ESG investing holds enormous potential, mature applications still face challenges. These challenges include current technical and market challenges, as well as new difficulties that may arise once theoretical frameworks are implemented.

#### **5.1. Differences in Data Standards**

Results from different rating agencies for the same company vary widely, making it difficult for investors to judge the reliability of information [18]. Even with data integration mechanisms, the timeliness and completeness of information are still insufficient. For example, Liu.M. found that greater quantitative ESG disclosure, especially disclosure on environmental and social pillars, results in greater divergence of ESG ratings [22]. This 'unstable source' can lead to biases in even the best algorithms.

#### **5.2. Difficulty of Capturing Investor Preferences**

Questionnaires and behavioral data can only reveal a partial picture, meaning that NLP struggles to quantify underlying values [10-11]. In practice, users may give socially desirable answers when filling out questionnaires, yet favor short-term returns when making investment choices [23]. This bias makes it difficult for the system to truly understand investors' true needs. In other words, even if preference identification is technically possible, in reality, what is said and what is done often differ.

#### **5.3. Algorithm Optimization**

Although multi-objective optimization and deep learning models have been proposed, their stability and interpretability remain insufficient. Complex deep learning models may overfit and provide unreasonable recommendations when faced with volatile market conditions. Furthermore, blackboxing makes it difficult for investors to understand the underlying logic. This is particularly sensitive in ESG investment scenarios, as users care not only about returns but also whether they align with their values [11,24].

## 5.4. Compliance and Regulation

Regulations on Robo-advisors and ESG investing vary significantly across different countries and regions [19]. For example, the United States places greater emphasis on investor protection, while Europe prioritizes mandatory sustainability disclosures [25,26]. This difference means that a product that complies with European regulations may not be successfully launched in the Asian market. Furthermore, greenwashing remains a widespread issue, with companies exaggerating their ESG performance to attract investment [18]. This behavior not only misleads investors but also undermines the trust foundation of the entire industry.

## 5.5. Future Problems

Even if the theoretical framework is successfully implemented, new problems will arise. For example, data fusion and algorithm optimization may require a large amount of computing resources, which will lead to a contradiction between technical costs and carbon emissions. For another example, the more accurate the preference identification, the higher the risk to user privacy. How the platform can find a balance between personalization and privacy protection remains an unresolved problem [27]. These problems show that there is still a long way to go between theory and practice. In summary, the challenges come from three levels: insufficient existing basic conditions (such as data and preference identification), risks of technical execution (such as algorithm stability and interpretability), and contradictions at the institutional and ethical levels (such as regulatory differences and privacy protection). These challenges determine that the integration of Robo-advisors and ESG will not be smooth, but from another perspective, they also provide direction for future research and practice.

## 6. Conclusion

The integration of Robo-advisors and ESG investing is becoming a key topic at the intersection of fintech and sustainable development. While their development paths diverge, they both reflect a shift in investor demand: not only pursuing returns but also seeking investments that reflect their values. Consequently, research and practice in this area are gradually coming to the forefront, garnering attention from both academia and industry.

From a technological perspective, Robo-advisors have transitioned from rule-based approaches to those relying on machine learning and big data. From a market perspective, ESG investing is moving from conceptual experimentation to widespread acceptance among mainstream investors. Combining these two approaches can expand the scope of Robo-advisors' services and make ESG investing more practical. This article reviews relevant research that, while promising initial results, remains fragmented and lacks systematic theoretical support.

To address this issue, this article proposes a converged framework. It emphasizes four core aspects: data integration, preference identification, algorithm optimization, and ensuring compliance and transparency. This framework is not an abstract slogan, but rather draws on recent empirical research and technical practice. Through this structure, researchers and practitioners can more clearly see the path to integrating Robo-advisors with ESG.

Of course, development in any field doesn't happen overnight. The previous analysis has revealed several difficulties: data inconsistency, capturing investors' true preferences, the "black box" problem of models, and differences in cross-market regulation. These difficulties remind us that future exploration requires multi-party collaboration. Technological progress is certainly important, but institutional innovation and investor education are equally indispensable.

Future research and practice will need to advance in these areas. With the gradual unification of data standards, the continuous improvement of algorithm interpretation capabilities, and the increasingly refined regulatory environment, this integration path in this process, the joint efforts of financial institutions, regulators, and academia will determine the speed and depth of this integration.

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