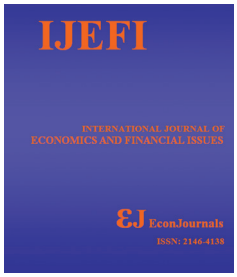

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# Constrained Minimum Variance Portfolio Considering Investors' Environmental, Social, and Governance Preferences

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**ABSTRACT**

Environmental, social, and governance (ESG) investing incorporates ESG factors into the investment decision-making process. By screening for companies with strong ESG practices, investors can potentially achieve long-term value growth and reduce the risk of corporate misconduct. In ESG investing, portfolio managers use a screened universe of stocks to construct portfolios based on financial risk and returns. At this point, the extent to which ESG factors are reflected in the portfolio allocation ratios becomes a black box. This study proposes a method for constructing an ESG portfolio that considers investors' ESG preferences. Investors' perceived importance of ESG is quantified using a hierarchical decision-making method. This measure is then applied as a constraint condition to determine stock investment ratios by solving a risk minimization problem. For a universe of 50 stocks, the Sharpe ratio of the constrained portfolio considering investors' ESG preferences was higher than that of the unconstrained portfolio.

**Keywords:** ESG Investment, Portfolio Optimization, Hierarchical Decision-Making
**JEL Classifications:** Q56, M14, M21

## 1. INTRODUCTION

Environment, social, and governance (ESG) factors are three crucial elements for sustainable corporate growth. These factors are important for evaluating a company's long-term value, as they impact stock performance (Frey and Oehler, 2014). Because ESG factors can influence a company's long-term financial performance and risk profile, they are attracting attention as criteria for investors' investment decisions (Xiao et al., 2023). As evidence that investors are seeking to incorporate these factors into their portfolios (Sakuma and Louche, 2008), sustainable investment assets under management in Japan increased by 59.2 % to JPY 493.6 trillion in 2022 from JPY 310.0 trillion in 2020 (HSBC Global Research, 2022). Moreover, the proportion of sustainable investing assets relative to total managed assets was 33.6% in 2022 compared to 24.3% in 2020.

Different index providers have discussed factors related to ESG policies (Mustafida and Fauziah, 2021; Hadiqa et al. 2024). ESG investing is an approach that focuses on these three non-financial aspects. Portfolio managers use these factors to screen companies as investment targets and select their investment universe. Negative screening excludes companies from investment consideration if they violate specific ESG-related criteria, while positive screening selects companies with high ESG ratings. Norm-based screening evaluates companies against international standards on issues like climate change, human rights, and labor issues, consistent with frameworks such as the United Nations Global Compact and OECD Guidelines for Multinational Enterprises. Fund managers use this investment universe to determine their investment targets and allocation ratios when building portfolios (Zhou and Palomar, 2020).

## 2. RELATED WORKS

Numerous studies have explored the relationship between ESG investment and financial performance. The correlation

between ESG factors, as indicated by ESG scores, varies. These relationships encompass positive correlations, negative correlations, and instances of no correlation between ESG factors and corporate financial performance. Friede et al. (2015) examine over 2,000 empirical studies and find that approximately 90% of them reveal a non-negative correlation between a company's ESG factors and its financial performance. Juthi et al. (2024) investigate the role of ESG data in corporate financial performance and investment decisions and find a positive correlation between higher ESG scores and higher long-term financial returns. A strong ESG proposition correlates with higher equity returns from both the tilt and momentum perspectives (Henisz et al., 2019). Companies on the Egyptian stock market that were ranked higher in ESG indexes have higher firm values, measured by Tobin's Q (Ahmed and Ahmed 2018). Quan and Zhou (2024) use a multiple regression model to analyze the relationship between financial performance, measured as return on assets (ROA), and ESG scores. They find a positive correlation between ESG performance and financial performance among Shanghai and Shenzhen listed companies from 2010 to 2020.

However, the positive impact of ESG factors on financial performance is limited. Galema et al. (2008) analyze the correlation between US portfolio returns, book-to-market ratios, excess stock returns, and ESG factors. They reveal that diversity and environmental factors negatively impact book-to-market ratios, whereas governance positively influences them.

Luo (2022) examines UK securities from 2003 to 2020 and finds that the overall ESG score significantly impacts stock returns. Firms with lower ESG scores outperform those with higher ESG scores in terms of value-weighted returns. However, the ESG premium is significant only for stocks with low liquidity. Moreover, while the premiums for social and environmental factors are significant, the governance premium is insignificant. Rosa et al. (2024) investigate the relationship between ESG risk scores and stock returns in the Indonesian LQ45 market from 2016 to 2022 but find that ESG factors do not significant impact stock returns. Duque-Grisales and Aguilera-Caracuel (2021) observe a statistically significant negative correlation between ESG scores and financial performance among Latin American multinationals in emerging markets, challenging the conventional wisdom that strong ESG practices lead to better financial outcomes.

These research results suggest that the relationship between ESG factors and corporate financial performance is not uniform and varies depending on the situation, revealing the need to set an appropriate investment universe for ESG investing. To set the investment universe, screening using ESG scores is performed. By constructing a portfolio for an investment universe established through appropriate screening, the risks and returns of ESG investing can be controlled. Verheyden et al. (2016) conduct a screening exercise in both global and developed market investment universes, excluding stocks in the bottom 10% of ESG scores. Portfolios constructed from the screened universe exhibited higher returns and lower risk, without a significant decrease in diversification potential. Jin (2022) shows that the overall risk of US equity portfolios decreased when funds with low return-based ESG scores were excluded.

Nakayashiki et al. (2017) perform a dual screening process using Japanese publicly traded companies, focusing on financial metrics and environmental performance. Companies with ROEs of <10% and those exhibiting an upward trend in environmental impact per unit of sales were excluded from the investment universe. The resulting portfolio outperformed the NIKKO Eco Fund (Louche and Sakuma, 2014); moreover, the risk of environmental efficiency fluctuations was mitigated. Zhang and Chen (2021) use ESG scores to perform a negative screen on a group of stocks. They predict the rate of return, screen for assets with high return potential, and then compare the annualized returns, Sharpe ratios, and ESG scores of these portfolios. The portfolios constructed through this double screening process consistently achieved high annualized returns and ESG scores, while also demonstrating strong performance in terms of the Sharpe ratio.

In the process of constructing a portfolio for an investment universe that has undergone screening based on ESG scores, information on investors' ESG preferences is lost. Fund managers and investors have a principal-agent relationship (Diniz, 2012). Individual investors are obliged to follow their agents' decisions and controlling these agents after the fact is difficult and costly (Gangi and Varrone, 2018). Investors have specific guidelines regarding which ESG factors should be prioritized and the criteria for stock selection. A survey conducted by van Duuren et al. (2016) shows that 43% of portfolio managers place the strongest emphasis on governance factors. Moreover, 60% have detailed instructions regarding governance factors, while 43% of investors have detailed instructions regarding both environmental and social factors. Due to the lack of a unified standard for ESG ratings, even companies with the same ESG performance can receive different ratings. This divergence in ESG ratings can result in pessimistic investor sentiment, leading investors to prefer investing in companies with smaller rating differences (Zhang, 2024).

In the process of selecting stocks through ESG screening and constructing a mean-variance approach portfolio, investors' ESG preferences become unclear, creating a principal-agent problem between fund managers and investors. Cheng et al. (2024) show that ESG performance and agency costs were negatively correlated from 2013 to 2022. Improvements in ESG value contributed to reducing agency costs and led to an increase in firm value, measured as ROA. Screening determines the investment universe based on the ESG criteria that investors prioritize. However, after asset selection in the portfolio construction process, the focus shifts to financial performance, and investors' ESG preferences are not considered (e.g., Markowitz, 1952; Zou et al. 2020).

Portfolio construction methods that reflect investors' ESG preferences have been proposed in prior research. Amon et al. (2021) propose a portfolio construction method where each stock's weight is determined by its relative ESG score within the universe, thereby aligning the portfolio with investors' ESG preferences. Schmidt (2022) seeks to determine the optimal portfolio weights that minimize risk while considering the intensity of investors'

ESG preferences. The objective function includes both return volatility and the proportional sum of the portfolio constituents' weighted ESG score, which represents the asset-weighted sum of ESG scores. By solving this optimization problem, Schmidt constructs a portfolio that aligns with both investors' ESG preferences and risk tolerance. Michael Fish et al. (2019) construct portfolios by adjusting returns based on ESG scores, giving greater weight to companies with higher ESG ratings during portfolio optimization. Investors' ESG preferences should be indicated for each ESG item; however, they are not always considered.

Previous studies have examined how ESG factors impact financial performance and risk. However, limited research has focused on incorporating ESG preferences into portfolio optimization. ESG investing focuses on screening companies based on ESG criteria. However, few methods are available for quantifying and incorporating individual investor ESG preferences into portfolio construction. This study addresses this gap by employing a hierarchical decision-making method to quantify ESG preferences and uses these preferences as constraints in a risk-minimization problem.

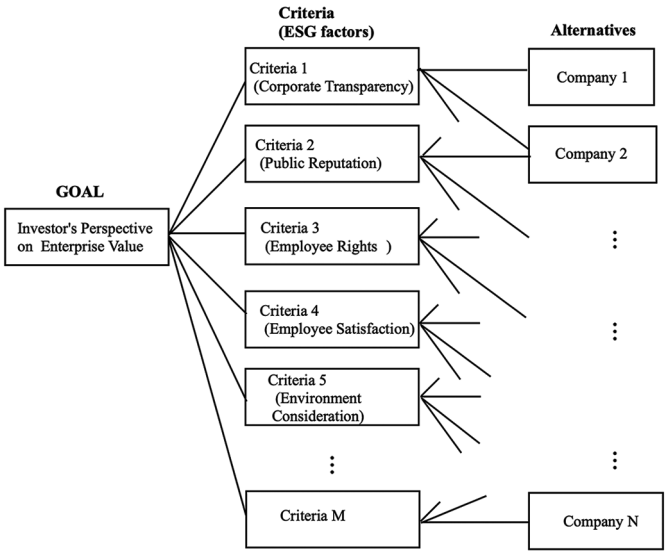
## 3. CONSTRAINED PORTFORIO CONSIDERING INVESTORS' ESG PREFERENCES

This study proposes a three-stage approach for constructing ESG portfolios.

### 3.1. Stage 1: Quantifying Investors' ESG Preferences

The analytic hierarchy process (AHP) (Saaty, 1990) is used to quantitatively understand which ESG factors investors prioritize. The AHP structure is illustrated in Figure 1. The overall objective (GOAL) is to maximize corporate value from the investors' perspective, with ESG factors as the evaluation criteria. The companies within the investment universe are the alternatives. Using pairwise comparison of the evaluation criteria relative to the overall objective, weights are assigned to each evaluation criterion. The geometric mean of these weights is then used to determine how much ESG factors contribute to corporate value.

**Figure 1:** AHP hierarchy




The importance each ESG factor has for corporate value is evaluated, and weights can be determined based on either expert opinions or questionnaire surveys. Table 1 shows the ESG preferences of investors based on pairwise comparisons. The geometric mean of the importance weight $W_{ij}$ is calculated from Table 1 to obtain the alternative weights of the ESG item factors (criteria) that investors consider important.

### 3.2. Stage 2: ESG and Financial Screening

The ESG factors are comprehensive assessments of ESG activities, as shown in Table 2. For example, transparency is evaluated using the following ESG activity value: number of consultants and advisors - number of internal whistleblowing cases. The ESG activity evaluation values are standardized and aggregated to obtain the ESG factor assessment for each criterion.

The overall ESG assessment of company k, considering investors' preferences, is shown in Eq. (1).

$$\frac{\sqrt[M]{\prod_{i=1}^{M} W_{1i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\sum_{i=1}^{L1} s_1(k,i)+\frac{\sqrt[M]{\prod_{i=1}^{M} W_{2i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\sum_{i=1}^{L2} s_2(k,i)+\cdots+\frac{\sqrt[M]{\prod_{1}^{M} W_{Mi}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\sum_{i=1}^{LM} s_M(k,i)$$

### 3.3. Stage 3: Building a Portfolio Considering Investors' ESG Preferences

We formulate the portfolio risk minimization problem with constraints on the contributions of ESG factors to corporate value. The lower bound of constraint (3) indicates that each company's ESG activity score is a value relative to the group of companies in the investable universe, weighted by alternative weights. Investors demand a portfolio inclusion ratio for each company that corresponds to the proportion of its ESG activity score's contribution to the investable universe's total ESG activity. The ESG preference priority parameter, α, indicates the degree to which an investor prioritizes ESG performance over financial performance. When ESG performance is the primary priority, α equals 1. Conversely, when only financial performance is considered, α is 0. In the latter case, the investors' ESG preferences are not reflected in the portfolio allocation ratio.

Minimize

$$\sigma_P = (x_1, x_2, \cdots, x_N)\sum\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{pmatrix} \quad (2)$$

**Table 1: Calculating the contributions of ESG factors to corporate value**

| Criteria | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 | Criteria 5 | | Criteria M | Geometric Mean | Alternative weight |
|---|---|---|---|---|---|---|---|---|---|
| Criteria 1 | 1 | $W_{12}$ | $W_{13}$ | $W_{14}$ | $W_{15}$ | ⋯ | $W_{1M}$ | $\sqrt[M]{\prod_{i=1}^{M} W_{1i}}$ | $\frac{\sqrt[M]{\prod_{i=1}^{M} W_{1i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}$ |
| Criteria 2 | $W_{21}=1/W_{12}$ | 1 | $W_{23}$ | $W_{24}$ | $W_{25}$ | ⋯ | $W_{2M}$ | $\sqrt[M]{\prod_{i=1}^{M} W_{2i}}$ | $\frac{\sqrt[M]{\prod_{i=1}^{M} W_{1i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}$ |
| Criteria 3 | $W_{31}=1/W_{13}$ | $W_{32}=1/_{W23}$ | 1 | $W_{34}$ | $W_{35}$ | ⋯ | $W_{3M}$ | $\sqrt[M]{\prod_{i=1}^{M} W_{3i}}$ | $\frac{\sqrt[M]{\prod_{i=1}^{M} W_{2i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}$ |
| Criteria 4 | $W_{41}=1/W_{14}$ | $W_{42}=1/_{W24}$ | $W_{43}=1/W_{34}$ | 1 | $W_{45}$ | ⋯ | $W_{4M}$ | $\sqrt[M]{\prod_{1}^{M} W_{4i}}$ | $\frac{\sqrt[M]{\prod_{i=1}^{M} W_{3i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}$ |
| Criteria 5 | $W_{51}=1/W_{15}$ | $W_{52}=1/_{W25}$ | $W_{53}=1/W_{35}$ | $W_{54}=1/W_{45}$ | 1 | ⋯ | $W_{5M}$ | $\sqrt[M]{\prod_{1}^{M} W_{5i}}$ | $\frac{\sqrt[M]{\prod_{1}^{M} W_{4i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}$ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋱ | ⋮ | | |
| Criteria M | $W_{M1}=1/W_{1M}$ | $W_{M2}=1/W_{2M}$ | $W_{M3}=1/W_{3M}$ | $WM4=1/W_{4}M$ | $WM5=1/W_{5}M$ | ⋯ | $W_{5M}=1$ | $\sqrt[M]{\prod_{1}^{M} W_{Mi}}$ | $\frac{\sqrt[M]{\prod_{1}^{M} W_{5i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}$ |

$W_{ij}$: Comparative evaluation values of the contribution to improving corporate value for Criteria i relative to Criteria j

Subject to

$$x_{k\geq}\alpha \frac{\sum_{m=1}^{M}\left[\frac{\sqrt[M]{\prod_{i=1}^{M} W_{mi}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\cdot ESG(k,m)\right]}{\sum_{k=1}^{N}\sum_{m=1}^{M}\left[\frac{\sqrt[M]{\prod_{i=1}^{M} W_{mi}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\cdot ESG(k,m)\right]}$$

$(k = 1,2, N)$ (3)

$\mu_p \geq RE$ (4)

$$\sum_{i=1}^{N} x_i = 1$$

$x_i \geq 0, (i = 1, 2, N)$ (5)

$\sigma_p^2$ : Portfolio risk (variance)

S: Variance-covariance matrix of stock returns

xi: Investment ratio to company i

mp: Expected portfolio return

RE: Required rate of return

ESG (k, m): Company k's ESG activity assessment for ESG factor m

α: ESG preference priority parameter

## 4. RESULTS AND DISCUSSION

### 4.1. Stage 1: Quantifying Investors' ESG Preferences

A survey was conducted among 600 domestic equity holders, asking them to assign weights to the activity criteria they consider important when selecting companies for investment, while ensuring that the total weight adds up to 100%. Table 3 shows the ESG preferences of investors based on pairwise comparison.

Investors prioritize corporate transparency relatively highly, while placing less importance on employee rights. The weights of other factors related to employee satisfaction are all <1. The maximum value is 0.7901, and the minimum value is 0.04644. The weights of factors related to transparency, relative to other factors, are all ≥1, with a maximum value of 2.1532 and a minimum value of 1.3818. Investors view environmental considerations, corporate transparency, and public reputation as nearly equally important.

Table 4 presents the ESG activities used to quantify ESG factors and their relative importance as perceived by investors. Investors' preferences indicate that governance accounts for 50% of the total (Corporate transparency: 29.01%, Public reputation 19.77%), while the environment (18.29%) is half as preferred as society (Employee rights: 13.87%, Employee satisfaction 19.09%).

**Table 2: ESG activity evaluation for ESG factors**

| ESG factors | ESG Activities | ESG Activity score for company k in Activity *i* | Company k's ESG activity evaluation value for ESG factor m; ESG (*k*, *m*) |
|---|---|---|---|
| Criteria 1 | $ACT_1$ | $s_1(k, 1)$ | $\frac{\sqrt[M]{\prod_{i=1}^{M} W_{1i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\sum_{i=1}^{L1} s_1(k,i)$ |
| | ⋮ | ⋮ | |
| | $ACT_{L1}$ | $s_1(k, L1)$ | |
| Criteria 2 | $ACT_1$ | $s_2(k, 1)$ | $\frac{\sqrt[M]{\prod_{i=1}^{M} W_{2i}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\sum_{i=1}^{L2} s_2(k,i)$ |
| | ⋮ | ⋮ | |
| | $ACT_{L2}$ | $s_2(k, L2)$ | |
| ⋮ | ⋮ | ⋮ | ⋮ |
| Criteria M | $ACT_1$ | $s_M(k, 1)$ | $\frac{\sqrt[M]{\prod_{1}^{M} W_{Mi}}}{\sum_{j=1}^{M}\sqrt[M]{\prod_{i=1}^{M} W_{ji}}}\sum_{i=1}^{LM} s_M(k,i)$ |
| | ⋮ | ⋮ | |
| | $ACT_{LM}$ | $s_M(k, LM)$ | |

**Table 3: Alternative weights of ESG factors to corporate value**

| | Environmental consideration | Employee rights | Employee satisfaction | Corporate transparency | Public reputation | Geometric mean | Alternative weight |
|---|---|---|---|---|---|---|---|
| Environmental consideration | 1 | 1.4165 | 0.8672 | 0.6578 | 1.1192 | 0.9801 | 0.1897 |
| Employee rights | 0.7060 | 1 | 0.6122 | 0.4644 | 0.7901 | 0.6919 | 0.1339 |
| Employee satisfaction | 1.1532 | 1.6335 | 1 | 0.7586 | 1.2907 | 1.1302 | 0.2187 |
| Corporate transparency | 1.5201 | 2.1532 | 1.3818 | 1 | 1.7014 | 1.4899 | 0.2883 |
| Public reputation | 0.8934 | 1.2655 | 0.7748 | 0.5877 | 1 | 0.8757 | 0.1694 |

**Figure 2:** Optimal portfolio

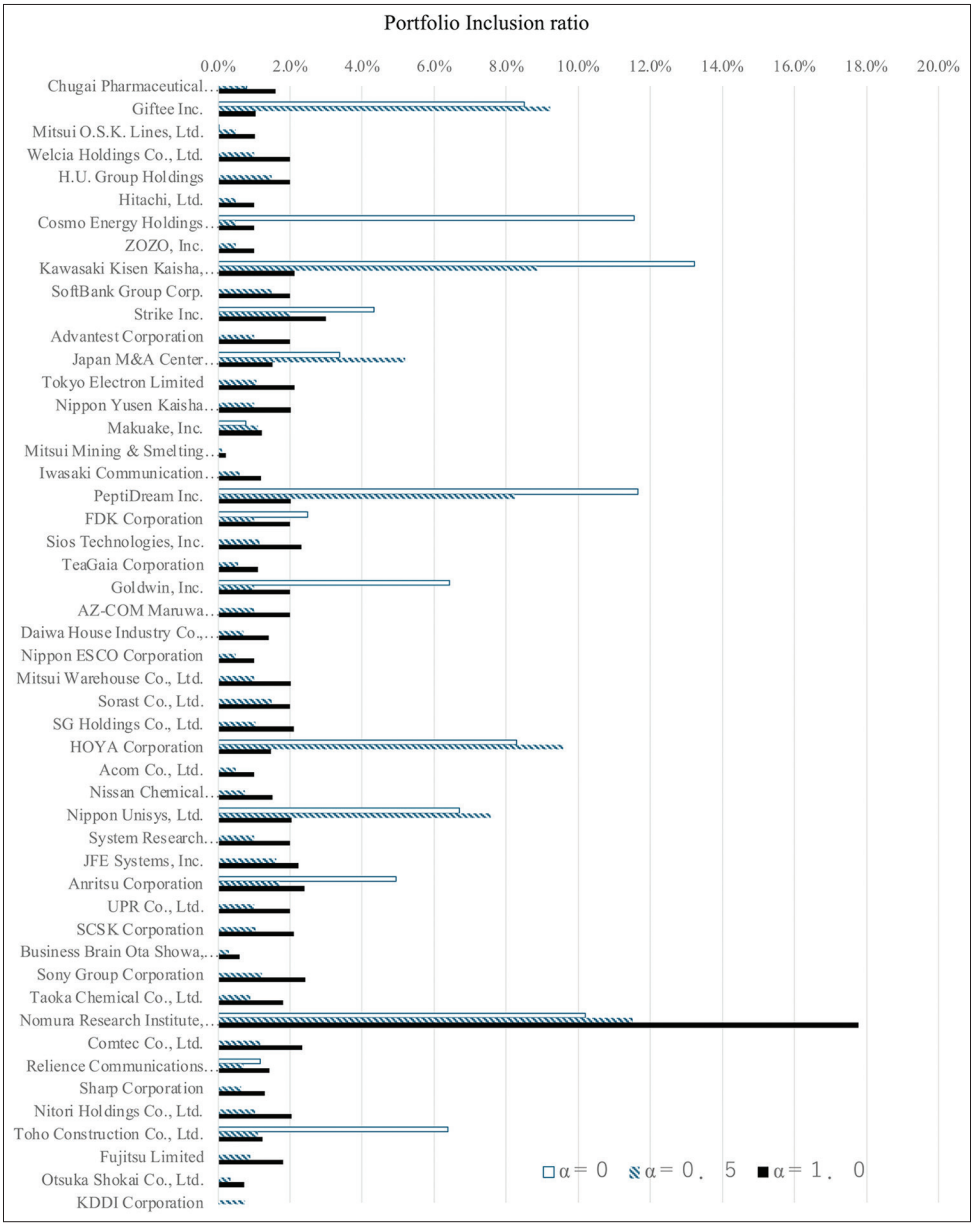



**Table 4: Investors' ESG preferences**

| ESG | ESG factors | Activity criteria | Significance (%) |
|---|---|---|---|
| E | Environmental consideration | Annual energy consumption | 18.29 |
| S | Employee rights | Percentage of female managers | 13.87 |
| | | Maternity/paternity leave usage rate | |
| | Employee satisfaction | Average employee salary | 19.09 |
| | | Average length of service | |
| G | Corporate transparency | Number of advisors and consultants | 29.01 |
| | | Number of whistleblowing incidents | |
| | Public reputation | Number of customer complaints | 19.77 |

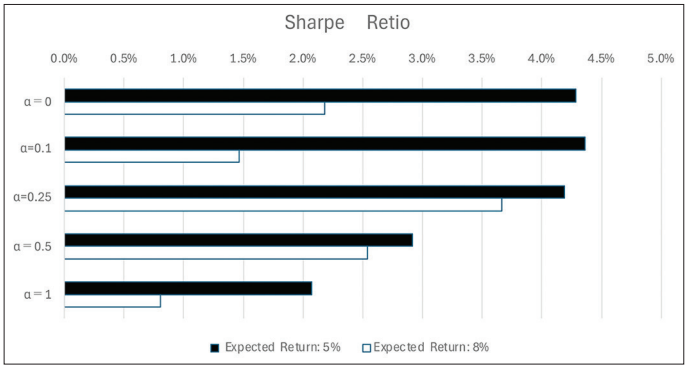
## 4.2. Stage 2: ESG and Financial Screening

We conducted a positive screening of 400 companies listed on the Tokyo Stock Exchange First Section, considering investor preferences for ESG factors (Shinposha 2022a; Shinposha 2022b; Shinposha 2023a; Shinposha 2023b). Subsequently, we further narrowed the universe to the top 50 companies based on ROE. Those companies are listed in Figure 2, ranked by their ESG scores from highest to lowest.

## 4.3. Stage 3: Building a Portfolio Considering Investors' ESG Preferences

We present the optimal portfolio for an investment universe consisting of 50 securities. The embedded ratios reflecting ESG preferences and financial performance can be confirmed (Figure 2). Among the 50 securities, 37 showed a tendency for the embedded ratio to increase as the investors' preference priority level increased.

**Figure 3:** Portforio performance




The performance of portfolios subject to ESG constraints is evaluated using the Sharpe ratio (Figure 3). The results indicate that when the expected return is 5% and the ESG preference parameter ($\alpha$) is set to 1, the ESG-integrated portfolio generates superior risk-adjusted returns compared to the benchmark. Similarly, for an expected return of 8%, the ESG-constrained portfolio outperforms the benchmark when $\alpha$ is 0.25 or 0.5.

## 5. CONCLUSION

Fund managers and investors have a significant principal-agent problem. Fund managers, whose compensation is often tied to the performance of the funds they manage, may prioritize short-term gains or personal interests over investors' long-term objectives. In contrast, investors frequently seek long-term wealth accumulation and are increasingly concerned about non-financial factors such as social responsibility and environmental impact.

By quantifying investor ESG preferences and incorporating these preferences in their portfolio construction, fund managers can enhance transparency and build trust with investors. Setting specific ESG goals and regularly reporting on progress can foster long-term relationships. This study pioneers a new approach in ESG investing by quantifying investor preferences and integrating them into portfolio optimization. The empirical analysis demonstrates that portfolios constructed with ESG constraints can produce higher risk-adjusted returns, suggesting that ESG considerations enhance overall portfolio performance without sacrificing returns.

Traditionally, ESG investing has focused on screening companies based on ESG criteria. However, few methods are available for quantifying and incorporating individual investor ESG preferences into portfolio construction. This study addresses this gap by employing a hierarchical decision-making method to quantify ESG preferences and then uses these preferences as constraints in a risk minimization problem. The resulting portfolios are tailored to meet the specific ESG preferences of individual investors.

By comparing the performance of ESG-constrained portfolios with that of traditional portfolios using the Sharpe ratio, the study finds that ESG-constrained portfolios often have higher risk-adjusted returns. This finding suggests that incorporating ESG factors can lead to improved investment outcomes without compromising returns.

This study demonstrates the feasibility of incorporating investor preferences into ESG portfolio optimization. The proposed method can help investors construct portfolios that align with their financial and ethical objectives.

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