

VSB - TECHNICAL UNIVERSITY OF OSTRAVA
Faculty of Economics, Department of Finance

**Financial Management of Firms and
Financial Institutions 2025**

15th International Scientific Conference

PROCEEDINGS

September 1-2, 2025
Ostrava, Czech Republic

ORGANIZED BY

VSB - Technical University of Ostrava, Faculty of Economics, Department of Finance

EDITED BY

Miroslav Čulík

TITLE

Financial Management of Firms and Financial Institutions 2025

ISSUED IN

Ostrava, Czech Republic, 2025

PAGES

94

ISSUED BY

VŠB - Technical University of Ostrava

DOI 10.31490/9788024848228

ISBN 978-80-248-4822-8 (on-line)

ISSN 2336-162X (on-line)

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Modern Perspectives on Portfolio Optimization

Valentina Piantoni¹, Sergio Ortobelli Lozza²

Abstract

This article examines portfolio optimization strategies that address both financial and ESG risks. First, portfolios are optimized to minimize financial risk using Conditional Value-at-Risk (CVaR), Mean Variance (MV) and Gini tools, that is a coherent risk measure that captures extreme market losses. After identifying portfolios with reduced financial risk, a second optimization is applied to further lower ESG risks, ensuring alignment with sustainability goals. By integrating both financial and ESG considerations, the approach produces portfolios that offer strong financial performance while meeting responsible investing criteria. Results show that ESG-coherent portfolios not only meet sustainability objectives but also exhibit competitive, resilient financial outcomes. This dual optimization process provides investors with portfolios that balance risk management with ethical investment principles.

Key words

Portfolio Selection, Risk Analysis, Sustainability, Investment Decision Making, Ethical Challenges.

JEL Classification: G11, G17, Q56, M14.

1. Introduction

Investors today are increasingly incorporating environmental, social, and governance (ESG) factors into their portfolio management strategies, driven by growing concerns over sustainability and the financial risks posed by environmental challenges. As the importance of addressing ESG risks becomes more evident, there is a pressing need to integrate these factors into traditional financial analysis. To achieve this, advanced risk measures, such as Conditional Value-at-Risk (CVaR), offer a more comprehensive approach by capturing both financial and ESG-related risks.

This article explores how ESG-consistent risk measures, particularly CVaR, can be applied to optimize portfolio selection, balancing financial risk with ESG risks like climate change, social responsibility, and governance issues. The study follows a two-step optimization process: first, portfolios are optimized to minimize financial risk using CVaR, and then, the focus shifts to further reducing ESG-related risks, ensuring that portfolios align with sustainability objectives. This dual optimization approach not only reduces financial risk but also integrates high ESG standards, resulting in portfolios that deliver both strong financial returns and positive sustainability outcomes. Garcia-Bernabeu et al. (2021) propose a multi-objective approach to minimize both ESG and financial risks, providing a robust framework for this dual optimization.

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The results of this study demonstrate that portfolios optimized with ESG-consistent risk measures not only align with investors' sustainability goals but also maintain competitive financial performance. The findings offer a valuable comparison to Torri et al. (2023), who also explore the integration of ESG factors using coherent risk measures. While their approach centers on the integration of ESG risks into a unified financial risk measure, this study provides a more detailed, two-step methodology that first addresses financial risk before focusing on ESG factors, offering a refined framework for sustainable investment optimization.

2. The two-steps portfolio optimization

The objective of this study is to perform a two-step optimization on various portfolios from the S&P 500 index. The aim is to minimize market risk, followed by ESG (Environmental, Social, and Governance) risk, using a linear Conditional Value-at-Risk (CVaR) approach. This approach is intended to identify portfolios that demonstrate both strong risk-adjusted returns and high ESG standards.

For this study, we collected historical daily price data for each asset in the S&P 500 index, covering a period from April 21, 2011, to December 30, 2021. This dataset provides a comprehensive view of each asset's performance and volatility over a 10-year timeframe. The data was sourced from Refinitiv and exported to Excel for subsequent processing in MATLAB. In addition to price data, we gathered daily ESG (Environmental, Social, and Governance) scores for each asset in the S&P 500 index, corresponding to the same 10-year period. These scores were divided into the three ESG pillars: Environmental, Social, and Governance, with each pillar scored individually for every underlying asset. This granularity allows for an in-depth analysis of ESG attributes over time. To consolidate the ESG data, we calculated the average of the three pillars (Environmental, Social, and Governance) for each asset, resulting in a composite ESG score. This composite score provides a single metric representing the overall ESG performance of each asset, making it suitable for use in the optimization process.

Step 1: First Optimization – Minimizing Market Risk

The first optimization phase focuses on minimizing market risk for portfolios derived from the S&P 500 index. This step adheres to the principles of Modern Portfolio Theory, leveraging Conditional Value-at-Risk (CVaR) to account for extreme market downturns beyond what traditional risk measures capture. By combining classical optimization with CVaR, this approach aims to construct portfolios that minimize exposure to both average market volatility and tail risks. Markowitz's Modern Portfolio Theory (1952) introduced the concept, demonstrating that diversification portfolio risk by selecting assets that behave differently. The portfolio selection involves minimizing risk (represented by the variance) and optimizing the reward (represented by the mean of returns). These two metrics serve as the foundation for constructing portfolios that balance risk and return. Risk measures are essential tools in portfolio management, providing a way to assess and manage financial risks. Traditional measures, however, may not fully capture the complexity of modern investment portfolios, particularly when incorporating ESG (Environmental, Social, and Governance) factors. One such measure that is both coherent and widely used is Conditional Value-at-Risk (CVaR), introduced by Rockafellar and Uryasev (2000). Morelli (2023) reinforces the importance of CVaR in ESG optimization, highlighting its effectiveness in balancing financial and environmental goals. Unlike Value-at-Risk (VaR), which focuses on the maximum expected loss within a confidence interval, CVaR captures the average loss during extreme events beyond the VaR threshold, thus providing a more complete view of tail risks.

In our study, we use CVaR to evaluate portfolios that account for both financial and ESG risks. The formula for CVaR is:

$$CVaR_{\alpha}(L) = \min_v \left\{ v + \frac{1}{1-\alpha} E[(L - v)^+] \right\} \quad (1)$$

where v is an auxiliary variable representing an estimate of the CVaR, $(L - v)^+$ is the positive part $L - v$, representing the losses beyond the level v , $E[(L - v)^+]$ is the expected value of the losses that exceed the threshold v , α is the confidence level of the VaR.

This formulation optimizes the CVaR by minimizing the auxiliary variable v , which acts as a cutoff for losses exceeding the VaR, thus capturing the expected extreme losses beyond that point. This approach is commonly used in optimization models to calculate the risk conditioned on extreme events. The CVaR function used in this study is linear and the portfolio is rebalanced daily, with the recalibration of 40 strategies occurring every trading day. This dynamic adjustment employs the most recent daily return data to capture evolving market conditions. The CVaR optimization is performed at three distinct confidence levels: 1%, 3%, and 5%, representing varying degrees of risk tolerance. For each of these levels, portfolios are optimized across 40 different average returns, from the global minimum CVaR till the maximum average return (resulting in 120 portfolios per day). The optimization problem is formulated as (for any given α):

$$\begin{aligned} & \text{Minimize: } CVaR_{\alpha}(R_p) \\ & \text{s. t. } E[R_p] \geq R_{target,k}, \\ & \sum_{i=1}^n w_i = 1, w_i \geq 0; i = 1, \dots, n; k = 1, \dots, 40 \end{aligned} \quad (2)$$

where $w = [w_1, \dots, w_n]'$ is the vector of the weights, $R = [R_1, \dots, R_n]'$ is the vector of returns, thus, $R_p = w'R$ is the portfolio of returns and $E[R_p]$ is the total expected return of the portfolio. This ensures that the portfolio meets a minimum target return $R_{target,k}$, varying for each of the 40 strategies, and it maintains full investment ($\sum_{i=1}^n w_i = 1$), and only holds long positions ($w_i \geq 0$). Thus, every day, for each alpha (1%, 3%, and 5%), we fit the mean- $CVaR_{\alpha}$ efficient frontier and we compute the ex-post wealth for each of the 40 strategies. We implicitly assume that any investor has a position on the efficient frontier obtained on that day corresponding to the target return. For any optimal portfolio we also consider the ex-post ESG of the portfolio given by $ESG_p = w'ESG$ where w is the vector of optimal weights while $ESG = [ESG_1, \dots, ESG_n]'$ is the vector of ex-post assets' ESG. The ex-post ESG portfolios will be used as the second step of optimization in order to minimize the ESG risk in the optimal choices.

Step 2: Second Optimization – Minimizing ESG Risk

Recently, ESG (Environmental, Social, and Governance) factors have gained prominence in portfolio selection due to their positive correlation with stable financial performance, as highlighted by studies like Friede et al. (2015). The integration of ESG considerations reflects the growing demand for responsible investment, balancing financial returns with environmental sustainability, social responsibility, and sound corporate governance. Advanced techniques such as machine learning and big data analytics, discussed by Chong et al. (2020), further enhance the ability to optimize portfolios beyond traditional models like the Capital Asset Pricing Model (CAPM) (see Sharpe (1964)). These advancements represent a shift toward holistic strategies that incorporate both financial metrics and ESG principles. The second optimization phase refines the portfolios obtained in the first phase by focusing on enhancing their ESG performance. This step ensures alignment with responsible investing principles while preserving the market risk minimization. In this phase we propose a reward-risk analysis where our reward measure is represented by the ESG portfolio scores, and the

risk is a coherent measure applied to ESG returns. We use the previous ex-post ESG scores we obtain by the 40 optimal strategies of step 1. On these scores we evaluate returns for each strategy, and we evaluate different ESG-CVaR strategies. The idea is to take portfolios of the optimal strategies of step 1 in order to reduce the ESG risk. Thus, as for step 1, we fit the ESG-CVaR efficient frontier at any recalibration considering 40 optimal portfolios and we repeat the optimization till we have finished all data. Unlike the first step, where the objective was to minimize CVaR under average return constraints, here the CVaR levels (1%, 3%, and 5%) are optimized with respect to ESG returns and instead of the average returns we fit the portfolio ESG (from the ESG of the global minimum CVaR, till maximum ESG). This results in nine combinations:

- CVaR 1% with ESG 1%, 3%, and 5%.
- CVaR 3% with ESG 1%, 3%, and 5%.
- CVaR 5% with ESG 1%, 3%, and 5%.

Mathematically, the optimization problem for this phase can be represented as:

$$\begin{aligned}
 & \text{Minimize: } CVaR_{\alpha}(R_{ESG,p}) \\
 & \text{s. t. } ESG_p \geq ESG_{target,k}, \\
 & \sum_{i=1}^n w_i = 1, w_i \geq 0; i = 1, \dots, n; k = 1, \dots, 40
 \end{aligned} \tag{3}$$

where $R_{ESG,p}$ is the portfolio return of the ESG w is the vector of weights in the portfolio and ESG_p is the portfolio's ESG score, calculated as the weighted average of the ESG scores of the individual optimal portfolio we get from step 1. The objective of this phase is to minimize the ESG risk valued as the CVaR of the ESG returns requiring that the obtained portfolio maintain an ESG greater than a ESG target ($ESG_{target,k}$) ensuring that the portfolio reflects strong environmental, social, and governance standards. The key point of this optimization is that it works exclusively on portfolios that have already been optimized in the first phase to minimize market risk through CVaR. Therefore, the risk profile of the portfolio, which addresses market volatility and extreme market events, is not altered in this phase. The focus is entirely on adjusting asset weights to minimize the ESG risk. Thus, the optimal portfolio that comes from this optimization minimizes the ESG risk of portfolios that minimize the market risk. The resulting analysis gives ex-post strategies with lower market risk and ESG risk. This optimization helps to identify those portfolios that consider both risk typologies reflecting dual commitment: they are not only resilient to market risk but also aligned with responsible investing practices, addressing ESG-related risks such as environmental impact, social responsibility, and governance issues.

3. Empirical results

The two steps empirical analysis have been applied to the components presented on the 30th of December 2021 in the S&P500. The results of this analysis have been reported in Figures 1 and 2 and in Table 1.

Figure 1: Ex-post wealth optimal mean-CVaR_{1%} portfolios.

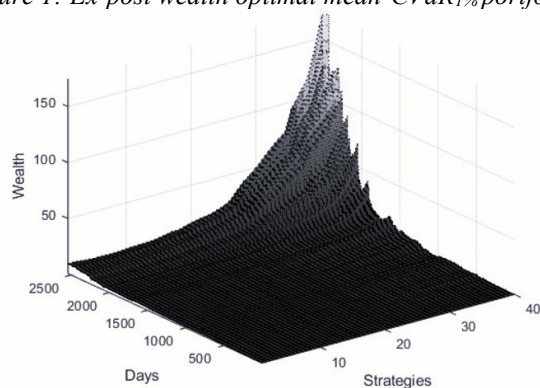


Figure 1 illustrates the three-dimensional representation of wealth evolution over almost 10-year period for the 40 strategies considered in our study, focusing on daily wealth growth with a Conditional Value-at-Risk (CVaR) of 1%. The graph highlights how wealth can grow up to 160 times the initial value by the end of the observed period. However, we use the components of the S&P500 present on the 30th of December 2021 and we do not change the components according to the quarterly changes of S&P500 components. Since the selected assets reflect the composition of the S&P 500 index at the final observation date, this approach did not involve rebalancing the S&P composition every three months. In addition, we observe that assets such as Netflix, Amazon, Tesla and many others which experienced extraordinary growth in the last decade, heavily influenced the outcomes. Some of these assets were not part of the S&P 500 at the start of the study but were included later. Their inclusion in the selection process, performed ex post (based on hindsight) rather than ex ante (forward-looking), led to an exaggerated and impractical wealth growth outcome. The use of CVaR at 1% indicates a higher level of risk aversion compared to 3% or 5%. Consequently, wealth outcomes for CVaR levels at 3% and 5% are even higher due to less conservative risk constraints. With larger alpha values (lower risk aversion), the average wealth values tend to increase significantly, along with more pronounced jumps in performance. When rotating the graph to analyze different periods, the effects of significant financial crises, such as the covid crisis, become evident. Riskier strategies show sharper declines in wealth during such events. Conversely, less risky strategies result in smaller losses, showcasing the trade-off between risk exposure and wealth preservation.

Figure 1: Ex-post wealth optimal ESG-CVaR_{1%} portfolios.

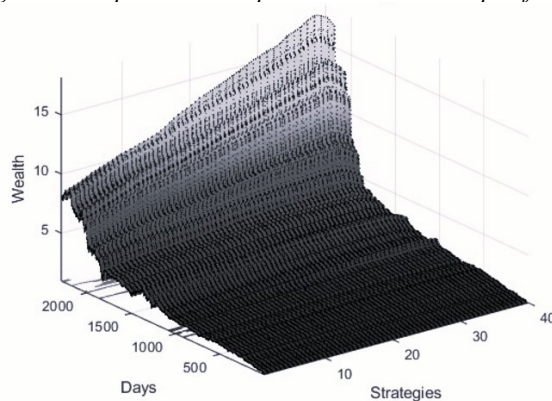


Figure 2 illustrates the evolution of wealth over almost 9 years depending on the investment strategy chosen, where 40 different strategies are analyzed. In this second step of

the analysis, the CVaR (Conditional Value at Risk) with a 1% threshold is already selected, and instead of fixing the mean return, the ESG score (Environmental, Social, and Governance) is used as the determining factor. The strategies now vary according to their ESG scores. Figure 2 demonstrates that selecting strategies with higher ESG scores minimizes risk and achieves substantial wealth. It indicates that starting with a strong ESG focus can lead to good wealth outcomes while maintaining a low-risk profile for both Market risk and ESG risk. Strategy 1 represents the global minimum CVaR strategy, which is the least risky as it minimizes overall ESG-related risk. This approach does not aim to maximize returns but chooses intermediate strategies that still minimize two sources of risk while achieving good wealth levels. Looking at the graph, we can observe that the maximum wealth attainable is approximately 16 times greater than the initial wealth. This result is achieved using Strategy 40, which corresponds to the highest ESG score strategy. In this analysis, the CVaR 1% threshold has been selected. The graph represents the pairwise 1%-1% strategy, meaning that CVaR at 1% was also chosen during the second step of optimization to produce this visualization. The first line in the graph corresponds to the global minimum CVaR, which does not prioritize ESG factors. In contrast, the last strategy focuses exclusively on one asset with the highest ESG score, which is inherently riskier but has the maximum ESG compliance. At the extreme end of the ESG optimization, only a single asset aligns with the highest ESG score, resulting in limited diversification but maximum alignment with ESG values. This visualization underscores the trade-offs between ESG prioritization, risk minimization, and wealth generation in long-term investment strategies. We summarize the results of step 2 in Table 1. Table 1 provides a detailed comparison of the performance metrics for two portfolio optimization strategies: one that focuses on minimizing Conditional Value-at-Risk (CVaR) and another that aims to maximize Environmental, Social, and Governance (ESG) scores. The results highlight key differences in portfolio outcomes across various combinations of CVaR and ESG thresholds, with particular attention to wealth, mean returns, and standard deviations (SD).

Table 1: Performance Metrics for Risk-Adjusted and ESG-Optimized Portfolios.

	Wealth		Sharpe Ratio		Standard Dev.	
	GM CVaR	Max ESG	GM CVaR	Max ESG	GM CVaR	Max ESG
1%,1%	8.08	15.08	0.0723	0.0759	0.014	0.0177
1%,3%	8.16	15.95	0.0733	0.0775	0.0138	0.0177
1%,5%	8.16	15.91	0.0733	0.0777	0.0138	0.0176
3%,1%	7.22	9.54	0.0700	0.0636	0.0137	0.0181
3%,3%	7.61	9.88	0.0713	0.0643	0.0138	0.0182
3%,5%	7.61	9.91	0.0713	0.0646	0.0138	0.0181
5%,1%	8.11	10.94	0.0722	0.0673	0.014	0.0179
5%,3%	7.86	11.21	0.0717	0.0683	0.0139	0.0178
5%,5%	7.86	11.18	0.0717	0.0684	0.0139	0.0178

Table 1 provides a detailed comparison of portfolio performance metrics under two optimization strategies: Global Minimum CVaR (GM CVaR) and Maximum ESG (Max ESG). Among these metrics, the Sharpe ratio plays a central role in evaluating the risk-adjusted returns of the portfolios. This ratio is calculated as:

$$\text{Sharpe Ratio} = \frac{R_p - R_f}{\sigma_p} \quad (4)$$

where R_p represents the portfolio return, R_f is the risk-free rate, and σ_p is the portfolio's standard deviation (volatility). The Sharpe ratio measures how much excess return a portfolio generates per unit of risk, with higher values indicating more efficient risk-adjusted performance. The results reveal a nuanced performance of Max ESG and GM CVaR portfolios across various combinations of CVaR (risk tolerance) and ESG thresholds. Max ESG portfolios achieve higher Sharpe ratios than GM CVaR portfolios only under the most risk-averse scenarios (CVaR at 1%), specifically for the pairs (1%,1%), (1%,3%), and (1%,5%). For instance, at the (1%,1%) threshold, Max ESG achieves a Sharpe ratio of 0.0759, exceeding the GM CVaR value of 0.0723. Similar trends are observed for (1%,3%) and (1%,5%), where the Max ESG Sharpe ratios are 0.0777 and 0.0776, compared to GM CVaR's 0.0733 and 0.0733, respectively. This advantage reflects the ability of ESG-compliant portfolios to balance financial returns with sustainability goals. By emphasizing investments in assets with strong ESG scores, Max ESG portfolios potentially reduce exposure to long-term systemic risks such as environmental or governance controversies. These risks, often overlooked in traditional financial optimization, could contribute to market stability and enhance the portfolio's overall resilience in the long term.

However, as the CVaR thresholds increase to 3% and 5% (indicating reduced risk aversion), the Sharpe ratios of Max ESG portfolios either converge with or fall below those of GM CVaR portfolios. For example, at the (3%,3%) level, the Sharpe ratio for Max ESG is 0.0646, compared to 0.0713 for GM CVaR. A similar trend is observed at (5%,3%) and (5%,5%), where the Sharpe ratio for Max ESG remains marginally lower than GM CVaR, reflecting a shift in the relative performance. This divergence at higher CVaR levels can be attributed to the underlying risk-return dynamics of ESG-compliant assets. At stricter CVaR thresholds, portfolios inherently restrict risk exposure, which may enhance the relative contribution of ESG-aligned assets to performance. However, as risk tolerance increases, the portfolio's diversification broadens, incorporating a wider set of assets that may dilute the incremental benefits of ESG optimization. Furthermore, ESG-focused portfolios often concentrate on sectors or companies with distinct risk-return profiles, leading to higher volatility (as evidenced by the higher standard deviations in Max ESG portfolios across all configurations).

The relationship between Sharpe ratios and CVaR levels also underscores a broader trend: both GM CVaR and Max ESG portfolios exhibit declining Sharpe ratios as CVaR thresholds increase. This reflects the nature of risk-adjusted performance, where portfolios optimized under lower CVaR levels are inherently designed to minimize extreme losses, leading to higher efficiency in generating returns per unit of risk. As CVaR thresholds rise, the relaxation of risk constraints allows for more aggressive allocation strategies, which may result in lower risk-adjusted returns despite higher absolute returns or wealth.

In conclusion, the Sharpe ratio analysis highlights the strengths and limitations of ESG integration in portfolio optimization. Max ESG portfolios deliver superior risk-adjusted returns under stringent risk constraints, demonstrating their potential to align financial performance with sustainability objectives. However, the diminishing advantage at higher CVaR levels points to the need for careful calibration of ESG considerations, particularly for investors with lower risk aversion. These findings illustrate that while ESG strategies can enhance long-term performance, they also require a nuanced understanding of the trade-offs between risk, return, and sustainability goals. For investors, this analysis provides valuable insights into constructing portfolios that balance financial resilience with responsible investment practices.

4. Conclusions

This study underscores the potential and challenges of integrating financial risk and ESG (Environmental, Social, and Governance) factors into portfolio optimization. Using a two-step methodology, the research demonstrates how minimizing financial risk via Conditional Value-at-Risk (CVaR) can be effectively combined with maximizing ESG scores to construct portfolios that align with both sustainability and financial performance objectives. The analysis also integrates key findings on wealth, Sharpe Ratios, and risk profiles from empirical results and visualizations.

The findings reveal that portfolios optimized for ESG factors consistently achieve superior wealth compared to those focused solely on minimizing CVaR. ESG-focused strategies exhibit higher Sharpe Ratios than GM CVaR portfolios. These results suggest that portfolios prioritizing ESG factors not only align with ethical standards but also enhance risk-adjusted financial performance, mitigating long-term systemic risks.

However, ESG-focused portfolios display higher levels of risk, as indicated by their increased standard deviations. This finding highlights a trade-off where investors must accept higher portfolio volatility to achieve enhanced ESG alignment and financial rewards. Graphical analyses illustrate distinct trade-offs between minimizing market risk and maximizing ESG alignment. The transition from GM CVaR to Max ESG strategies involves moving toward less diversified portfolios with greater ESG compliance but heightened exposure to specific assets. The results underscore the importance of tailoring portfolio strategies to varying risk tolerances. Investors with higher risk aversion may prefer GM CVaR strategies for more stable risk-adjusted returns. In contrast, those with a higher tolerance for volatility may benefit from ESG-maximized strategies, which yield higher returns despite their risk profile.

The dual optimization analysis demonstrates that ESG integration enhances portfolio resilience and risk-adjusted performance, while offering practical insights into navigating the trade-offs between financial risks, return potential, and ESG compliance. These findings contribute to the growing field of sustainable finance by demonstrating that ESG integration is not merely an ethical choice but also a financially sound strategy. The outperformance of ESG-optimized portfolios confirms the viability of combining financial and ESG objectives in portfolio management.

The integration of financial and ESG risks through dual optimization represents a forward-looking approach to investment management. By balancing risk, return, and sustainability, this methodology delivers not only resilient portfolios but also a commitment to ethical investment practices. These strategies pave the way for a more sustainable financial future, catering to the growing demand for responsible investing.

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