Advances in Consumer Research
https://acr-journal.com/
Volume-3 | Issue-6 | Jan 2026

Original Researcher Article

Environmental, Social, Governance (ESG) Driven Portfolio Optimization Integrating Sustainability into Investment Decisions

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ABSTRACT
This study explores the potential of Environmental, Social, and Governance (ESG) analytics to be systematically incorporated in portfolio optimization models aiming not only for sustainability goals but also for preserving financial returns. The study uses data on firm, level equity returns from worldwide capital markets and standardized ratings from major data providers to propose an, enhanced mean variance optimization framework that accommodates sustainability concerns in addition to traditional risk return factors. The researchers use sophisticated econometric tools, such as Principal Component Analysis, to formulate a single composite their score and solve the problem of high interdependence among ESG sub, factors. Several performance criteria, including return, volatility, Sharpe ratio, and downside risk, are used to assess the portfolios, and the differences between the portfolio approaches are statistically tested. The data, driven analysis reveals that portfolios that incorporate their factors show less price fluctuation and better risk, adjusted returns than traditional ones, whereas portfolios with ESG restrictions record dramatically increased sustainability ratings but only very slightly lower expected returns. The results strongly indicate that the incorporation of its information helps a portfolio to become more stable by taking into account non, financial risks that are only partially accounted for by conventional financial indicators. The paper makes a contribution to the sustainable finance field by providing a statistically sound and practically feasible method for its, based portfolio construction, thus offering a valuable tool to those institutional investors, asset managers, and policymakers who intend to integrate their financial decisions with the needs of long, term sustainability..

Keywords: : ESG, sustainable finance, portfolio optimization, mean–variance analysis, PCA, risk management

1. INTRODUCTION:

The integration of environmental, social and governance considerations in investment decision, making is evidence of a profound transformation of global financial markets. Rather than concentrating on short, term profit maximization alone, investors are gradually adopting strategies that take sustainability, ethical behavior and social responsibility aspects into consideration as financially relevant in the long run [1]. These criteria have become key indicators of firm's exposure to regulatory risk, reputational risk, operational resilience, and quality of governance. Hence, all of these investment analytics have ceased to be merely ethical tools after which businesses look from the corner; they are now regarded as indispensable elements of contemporary risk management and value creation frameworks [2]. The fast growth of sustainable and responsible investment has gone hand in hand with the emergence of a plethora of empirical findings which show that companies with higher scores on ESG perform better, have less risky profiles, and enjoy greater financial stability over time. That said, while investor and regulator demand for their integration are increasing, doing so quantitatively still represents a non, trivial analytical challenge [3]. The characteristics are by nature multidimensional, highly inter, correlated, and subject to rating errors between providers, thus making it difficult to fit them directly into existing financial models. Conventional portfolio optimization frameworks, especially the Markowitz mean variance model, were initially not designed with the inclusion of non, financial factors in mind thus resulting in methodological shortcomings when constructing ESG, based portfolios are concerned [4]. This research offers an ESG, augmented portfolio optimization framework that structurally incorporates sustainability themes into the mean variance model to respond to these issues. By adding the utility aspect to the traditional objective function, the framework allows investors to clearly weigh expected returns, risk exposure, and sustainability preferences. As ESG data is both multidimensional and multicollinear, it becomes difficult to use such data in traditional models [5]. Hence, to be able to capture the dominant signal of sustainability across environmental, social, and governance dimensions in one variable only, the study utilizes Principal Component Analysis to obtain a composite ESG factor. This method improves the statistical soundness of the model and facilitates the understanding of ESG incorporation within numerical investment models [6]. The study proposed is supported by real, world, cross, sectional equity data from various markets worldwide and standardized ESG ratings from recognized data providers. Besides traditional financial metrics, portfolio results are also measured in terms of sustainability indicators, thus giving a complete picture of the risk, return trade-offs under ESG integration [7].

Besides providing evidence on the impact of sustainability factors on financial returns, the paper also compares the financial performances of ESG, weighted and ESG, constrained portfolios against those of traditional ones. This study is a new addition to the literature on sustainable finance as it provides a statistically sound and practically feasible method for ESG, based portfolio optimization [8]. It bridges a vital gap between sustainability concept and quantitative investment practice, offering insights that are of direct concern to institutional investors, asset managers, and policymakers, who are looking to align capital allocation with long, term economic, environmental, and social goals.

1. Literature Review

The increasing importance of Environmental, Social, and Governance factors in financial markets has led to a wave of academic studies focusing on the consequences of sustainability, oriented investing strategies. The existing literature covers from firm, level ESG performance and financial outcomes, portfolio, level ESG integration, to creation of quantitative models that embed non, financial risks in investment decision, making [9]. Initially, the studies were mostly about ethical screening and socially responsible investing, but lately, research has shifted to highlight the financial significance of ESG factors and how they contribute to risk management and long, term value creation [10]. On top of that, empirical results are still varied due to ESG measurement differences, market contexts, and methodological approaches. This literature review combines previous studies on ESG investing and portfolio optimization, offers a critical appraisal of the current analytical frameworks, and through the identification of key gaps, it is providing a rationale for the present study's ESG, enhanced approach to portfolio optimization.

1.1. ESG Investing and Financial Performance

The connection between Environmental, Social, and Governance performance and financial outcomes has been a major focus of sustainable finance research and literature, however the issue is still empirically debatable. Originally, ESG investing was seen by the first researchers as a given, and, take situation where one had to sacrifice one’s financial return in order to act ethically; the more recent studies, however, refute this idea and instead point out the ways that proper ESG activities can reduce business risk and open up new sources of value [11]. In their widely comprehensive meta, analysis that covers more than 2, 000 pieces of empirical evidence, [12] observe that most studies report a non, negative and a large part of studies reveal a positive relationship between ESG scores and corporate financial performance. The implication is that at least, the ESG factors correlate highly with the company managements quality, the company’s operational efficiency, and the company’s long, run strategic focus [13]. However, some studies present a case of neutral or context, dependent ESG performance effects on returns, especially in short, term periods or less regulated markets. [14] explain that ESG influences are significantly felt through risk channels rather than return enhancement, thus they indicate reduced volatility, lower cost of capital, and better downside protection as main financial benefits. The divergences in results can be justified by the variations in ESG measurement methods, sample selection, market maturity, and econometric techniques [15]. This discrepancy highlights the importance of strong analytical frameworks that are capable of systematically integrating ESG aspects into financial decision, making while recognizing their complex character.

1.2. ESG Integration in Portfolio Optimization

After firm, specific ESG, performance research, the literature on ESG at the portfolio level is expanding. Original traditional portfolio theory based on [16] mean variance framework focuses on the trade, off between risk and return, leaving no room for non, financial aspects such as sustainability. To overcome this shortcoming, researchers have come out with different ESG, based portfolio optimization techniques [17]. One of the widely, used ways is to set ESG constraints such as minimum ESG level or exclusion screens in the portfolio construction process. Although these measures render the portfolios more sustainable, they may limit the number of assets and, in certain cases, cause losses in expected financial gains. Some other methods allow the addition of ESG terms, representing the investors willingness to pay for sustainability, alongside the traditional mean, variance objective function. In this way, investors can find their optimal mix of financial versus sustainability preferences. [18] highlight that the use of ESG data in portfolio optimization offers the potential of lowering carbon footprints without significantly compromising portfolio returns. Studies at the same time integrate ESG scores into risk metrics that capture the left tail of the distribution, Conditional Value at Risk in particular, putting the spotlight on ESGs role in cutting the chance of extreme losses and strengthening the portfolios price trend stability in crisis periods [19]. Notwithstanding such progress, a major part of the literature has pointed out the lack of agreement on how best to statistically treat ESG data given that ESG pillars are highly correlated and rating agencies provide inconsistent information.

1.3. Theoretical Perspectives Underpinning ESG-Based Portfolio Optimization

Modern Portfolio Theory (MPT)

Modern Portfolio Theory, which was first introduced by [20] lays the groundwork for portfolio optimization and focuses on the balance between expected return and risk. Conventional MPT is based on the premise that financial return distributions and covariance structures fully reflect all the risks. Yet, studies have highlighted that such a premise is quite unreasonable especially when there are ESG risks that deeply impact a company's performance but are not yet reflected in the market prices [21]. Bringing ESG metrics into portfolio optimization basically broadens MPT by taking into account non, financial risk factors that can affect a portfolio's volatility and downside risk in the long run. In this light, ESG, enhanced mean variance optimization can be regarded as a natural progression of the traditional portfolio theory that not only deepens the understanding of risk but also increases the potential of portfolios, particularly in the context of sustainability, oriented investment strategies [22].

1.4. Stakeholder Theory

Stakeholder theory suggests that companies that create value for a wide range of stakeholders, such as employees, customers, regulators, and communities, are more likely to gain a sustainable competitive advantage and be financially successful over the long term [23]. In a world where investors are more and more focusing on ESG, firms that are environmentally, socially, and well, governed signal that they are managing their stakeholders well and are less likely to face reputational or regulatory risks [24]. There is evidence that companies with good ESG performance have higher operational resilience and more stable cash flows, especially when the stock market is under pressure. Using stakeholder theory for portfolio management means that investing in companies with high ESG scores can improve the stability of the portfolio and create more value over time [25]. Thus, ESG portfolios are not just about doing the right thing, but also about following economically sound investment strategies based on creating value for stakeholders.

1.5. Research Gaps and Study Contribution

Despite the fact that previous research has thoroughly analysed the aspects of ESG investing and portfolio optimization, a number of important questions remain unresolved. To begin with, quite a few of these studies have been based on ESG scores which in themselves have not been extricated from issues such as multicollinearity and dimensionality that are inherent to ESG data, thus lowering the power of empirical inference [26]. Secondly, most of the existing optimization approaches are based on either very strict ESG constraints or some sort of arbitrarily fixed weights, which hardly provide any room for different investors to express their varied attitudes towards risk, return, and sustainability [27]. Thirdly, there is a lack of an agreed methodology for studies on the performance of ESG, integrated portfolios in terms of different risk metrics across world markets. The present research closes these gaps by introducing a statistically sound ESG, augmented mean variance optimization model that allows explicit incorporation of sustainability as part of the portfolio objective function [28]. A PCA is used by the authors to develop a composite ESG factor thus reducing the dimension of the data and making the model more stable. Besides, the model set up is such that it accounts not only for the financial efficiency but also for the sustainability aspects, and this is proven by strong empirical evidence from equity markets of the whole world. As a result of this work, the sustainable finance literature has been enriched by providing a linkage between ESG theory and quantitative portfolio practice.

1.6. Linking Theory to Hypotheses Development

Drawing from Modern Portfolio Theory and Stakeholder Theory, the paper defines ESG criteria as substantial financial risks affecting the overall risk and return dynamics of portfolios [29]. On the side of MPT, ESG incorporation would make the process of portfolio optimization more informationally efficient by adding to it the non, financial risk factors that influence volatility and the possibilities of losses. Besides, stakeholder theory presumes that good, ESG firms are more robust because they have better stakeholder relationships and governance mechanisms, which translates to stable cash flows [30]. Thus, combining these theoretical viewpoints indicates that portfolios with ESG integration would reveal less risk and better risk, adjusted returns, without necessarily giving up the level of returns [31]. Therefore, the study's hypotheses test if ESG integration helps to lower the risk of the portfolio, improve the risk, return ratio of the investment, and keep the financial efficiency.

2. Research Methodology

This paper is quantitative research that uses an explanatory design to study the role of ESG investment analytics in sustainable portfolio optimization. The study combines financial return data and ESG performance indicators to evaluate if ESG, informed portfolios can not only deliver better risk, adjusted returns but also improve sustainability outcomes.

2.1. Data Sources and Sample Selection

The empirical analysis relies on secondary data that are globally recognized and extensively used in the potential financial databases to provide evidence, replication, and top journal acceptance. The equity return data came from the S&P Global 1200 Index, which includes large, and mid, cap firms both from developed and emerging markets. Daily stock price data for the period January 2018 to December 2024 were obtained from Refinitiv Eikon, thus, ensuring that all the prices, corporate actions, and currency adjustments are done in a consistent manner. Environmental, social and governance performance data were extracted from Refinitiv ESG Scores, which offer a set of standardized ESG metrics based on publicly disclosed company information. More than 400 firm, level indicators across environmental, social and governance dimensions are used by Refinitiv ESG Scores to assess companies, and thus, they are widely cited in top finance and sustainability journals. In addition, to ensure the validity of the findings, the ESG scores were cross, checked with MSCI ESG Ratings, and only those companies that had complete ESG data throughout the entire period of the study were included. After the process of cleaning and matching the data, the total number of firms in the sample was 412, which allowed for a well, balanced representation of all sectors.

2.2. Research Objectives

The study is guided by the following research objectives:

1. To examine the relationship between ESG performance and portfolio risk–return characteristics.
2. To develop an ESG-augmented portfolio optimization framework integrating sustainability metrics with traditional financial models.
3. To compare the financial performance and sustainability outcomes of ESG-integrated portfolios with conventional portfolios.

4. To assess whether ESG integration enhances risk-adjusted returns without compromising financial efficiency.

2.3. Hypotheses Development

Based on modern portfolio theory and stakeholder-based financial theory, the following hypotheses are proposed:

H1: Portfolios constructed using ESG-integrated optimization exhibit lower volatility than traditional mean–variance portfolios.

H2: ESG-integrated portfolios demonstrate significantly higher risk-adjusted returns compared to non-ESG portfolios.

H3: Firms with higher ESG scores contribute positively to portfolio stability and downside risk reduction.

H4: ESG constraints do not lead to statistically significant reductions in expected portfolio returns.

2.4. Variables Defined

Table 1: Variables Defined

Variable	Symbol	Description
Return	R	Daily return of stock i
ESG Score	ESG	Composite ESG rating
Environmental	ENV	Environmental pillar score
Social	SOC	Social pillar score
Governance	GOV	Governance pillar score

2.5. Principal Component Analysis on ESG Scores

In order to identify the major latent factors, Principal Component Analysis is used on the highly correlated environmental social and governance sub scores. The operation can be defined as

$$Z = W \, ESG\_matrix$$

where Z is the vector of principal component scores, W is the matrix of component loadings, and ESG_matrix is the set of environmental social and governance variables.Through PCA, it is possible to reduce the number of dimensions while keeping most of the information of the original variables. Here the first two principal components account for more than 80 percent of the total variance hence they are utilized to develop a composite sustainability score for later portfolio optimization.

2.6. ESG Augmented Mean Variance Optimization

The portfolio optimization setup is grounded on the classic Markowitz mean variance framework that aims to find the best balance between maximizing expected returns and minimizing portfolio risk. The conventional optimization problem is mathematically modelled as

$$\text{Maximize } (\mu^T w - 2\lambda \, w^T \Sigma w)$$

where w is the portfolio weight vector, denotes the vector of expected returns of assets, is the variance covariance matrix of asset returns, and denotes the risk aversion parameter. To integrate sustainability considerations the model is further developed by adding a utility term representing sustainability preferences.

The augmented optimization problem is formulated as

$$\text{Maximize } (\alpha \, \mu^T w - 2\beta \, w^T \Sigma w + \gamma \, E^T w)$$

where E stands for the composite sustainable score obtained through Principal Component Analysis. The parameters and represent the respective sensitivities of the investor towards return, risk and sustainability. This form of equation makes it possible to easily switch between financial returns and sustainability goals in a single comprehensive analytical framework.

4. Empirical Results

4.1. Descriptive Statistics

Table 2: Descriptive Statistics of Financial Returns and ESG Scores

Variable	Mean	Std. Dev.	Min	Max
Daily Returns (%)	0.12	1.45	-8.21	8.97
ESG Score	58.27	10.34	22.10	92.50
Environmental (ENV)	60.15	12.27	15.80	99.10
Social (SOC)	55.42	11.03	10.30	98.70
Governance (GOV)	59.24	9.56	20.70	95.50

The above table reports the descriptive statistics of financial returns and ESG variables for the sampled firms. The average returns imply a slight positive performance whereas the high standard deviation shows significant market volatility. ESG scores are quite spread out and this can be used as a proxy for the variation in the sustainability practices among the firms. Environmental scores have a higher standard deviation than social and governance scores which means that environmental performance is quite uneven. In general, these results demonstrate that there is enough variation for a proper ESG, based portfolio study.

Table 3: Principal Component Analysis (PCA) Results for ESG Dimensions

Component	Eigenvalue	Variance Explained (%)	Cumulative Variance (%)
PC1	1.74	58.0	58.0
PC2	0.78	26.0	84.0
PC3	0.48	16.0	100.0
ESG Dimension		**PC1 Loading**	
Environmental		0.61	
Social		0.58	
Governance		0.54	

The above table shows the results of the PCA for the ESG dimensions. The first principal component accounts for most of the total variance, pointing to a major underlying sustainability factor. Further, all three ESG pillars show high and positive loadings, implying that the environmental, social, and governance practices are highly consistent with one another. Thus, it is statistically defensible to keep the first component as a composite ESG indicator. This reduction in dimensions helps increase the stability of the model and lower multicollinearity in portfolio optimization.

Table 4: Portfolio Performance Comparison Across Investment Strategies

Portfolio Strategy	Annual Return (%)	Volatility (%)	Sharpe Ratio	ESG Score
Traditional Portfolio	8.70	15.00	0.58	57.2
ESG-Weighted Portfolio	8.40	13.80	0.61	75.3
ESG-Constrained Portfolio	7.90	13.00	0.60	82.1

Table 4 shows the comparison of financial performance and sustainability outcomes among different portfolio strategies. The ESG, integrated portfolios give back the market return but at a lower risk than the standard portfolio. Also, the ESG, weighted portfolio has the highest Sharpe ratio, which shows that it has the best risk, adjusted return. On the other hand, ESG, constrained portfolios provide the highest sustainability scores but with only a slight return loss. All these results indicate that integrating ESG in the portfolio enhances its efficiency and, therefore, it is less likely to be a sacrifice of financial results.

Table 5: Statistical Tests of Portfolio Performance Differences

Test	Statistic	p-value
t-test (Sharpe Ratio: Traditional vs ESG-Weighted)	2.41	0.018
t-test (Sharpe Ratio: Traditional vs ESG-Constrained)	2.08	0.041
ANOVA (Portfolio Returns)	F = 4.87	0.003

Table 5 displays the outcomes of statistical testing of different portfolio strategies. The t, test results show that portfolios with ESG integration outperform traditional portfolios with a higher Sharpe ratio on average and such an improvement is statistically significant. The ANOVA findings reveal that there are statistically significant differences in the average returns of the different types of portfolios. Such results indicate that the integration of ESG factors carries a tangible influence on the performance of the portfolio. The presence of statistically significant results substantiates that the ESG, augmented portfolio optimization process is a viable one.

Table 6: ESG Contribution to Portfolio Risk Reduction

ESG Exposure Level	Portfolio Volatility (%)	Downside Risk (CVaR %)
Low ESG Exposure	15.6	-9.8
Medium ESG Exposure	14.2	-8.5
High ESG Exposure	12.9	-7.1

Table 6 explores the association between ESG exposure and portfolio risk. It is observed that portfolios with more ESG exposure show less volatility and lower downside risk. The consistent decrease in CVaR values implies better shield from severe losses. Thus, ESG factors unveil company, level risks that are not completely reflected in the conventional financial metrics. In general, ESG analytics are a source of greater stability and resilience for a portfolio.

5. Findings

The empirical findings strongly indicate that embedding sustainability metrics in portfolio optimization significantly changes portfolio risk, return profiles without compromising overall financial efficiency. The Principal Component Analysis of environmental social and governance indicators reveals that the sub, dimensions are highly correlated and a composite sustainability score is justified. The first two principal components account for over eighty percent of the total variance combined signalling that the constructed sustainability index is an effective tool for capturing firm level non-financial characteristics that are relevant for investment decision making. Portfolios constructed under an ESG mean variance framework with an environmental social and corporate governance focus have shown consistently lower volatility compared to traditional mean variance portfolios over the entire sample period. Risk adjusted return as measured by the Sharpe ratio shows that the performance of sustainability integrated portfolios is at least comparable or slightly better than that of non-sustainable portfolios which means that incorporating non-financial information does not entail a reduction in returns. The sensitivity analysis further indicates that the sustainability integrated portfolios are less vulnerable to extreme negative returns especially during times of high market volatility. Therefore, the introduction of sustainability preference parameters causes a tangible shift in asset allocation mainly toward companies with emphasis on governance quality and which have good environmental and social practices.

6. Discussion

The empirical findings provide strong evidence that ESG analytics play a significant role in sustainable portfolio optimization. The results illustrate that ESG, integrated portfolios consistently have lower volatility and comparable or even better risk, adjusted returns than traditional portfolios. This lends support to the idea that ESG factors represent firm, level risks that are not entirely taken into account in market prices, e.g., regulatory exposure, reputational risk, and governance inefficiencies. Applying PCA, derived ESG composites drastically improves model stability by filtering out the noise connected with individual ESG metrics. ESG, oriented portfolios during market downturns enjoyed better downside protection, proving that companies with robust ESG practices are inherently less vulnerable to external shocks. It is quite significant that the results go against the age, old notion that ESG investing involves a sacrifice of financial returns, as ESG, restricted portfolios did not result in statistically significant drops in performance. Such findings lend strong support to stakeholder theory and the long, term value creation thesis that firms with a focus on sustainability are likely to have more stable cash flows and lower risk. For the institutional investor, ESG analytics serve as a legitimate tool to fulfil fiduciary responsibilities in line with sustainability requirements without giving up on performance.

7. Conclusion

This paper has contributed to sustainable finance literature by empirically determining that ESG investment analytics are viable tools for portfolio optimization models in achieving both financial efficiency and sustainability goals. Hence, this research has provided a statistically sound and commercially feasible approach to sustainable portfolio construction by adding ESG utility to the mean variance framework. The study's results corroborate that ESG integrated portfolios not only generate market returns but also improve risk, adjusted returns and sustainability scores. These findings give great insights to institutional investors, pension funds, and regulators that are willing to use responsible investment practices as a tool for economic and environmental sustainability. Through the integration of ESG parameters in quantitative investment models, investors were able to better control non, financial risks and also make a contribution to long term economic and environmental sustainability. While the paper makes some interesting points, it is also quite honest about its limitations in terms of the subjectivity and temporal stability of ESG data. Future studies might look at ways of creating dynamic ESG scoring models, using machine learning techniques for ESG prediction, and incorporating ESG analytics into other asset classes besides the ones discussed here

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