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Article

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The role of ESG-based assets in generating the dynamic optimal portfolio in Indonesia

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ABSTRACT

The aim of this study is to evaluate the role of Indonesia's ESG-based equities (represented by ETF SRI-KEHATI) in achieving optimal portfolio diversification with different asset classes, i.e. conventional assets (equities and government bonds), safe-haven assets (gold), commodities (crude oil) and digital assets (Bitcoin). The data used in the study was the daily return of each asset from January 2018 to December 2023, representing data from before, during and the recovery after the COVID-19 pandemic. The methodology consists of a four-step process using the Pruned Exact Linear Time algorithm, the DCC-GARCH model and quadratic programming optimization. The study implies that investment managers and investors can reduce investment risk and balance their portfolios by including ESG-based assets in their portfolios. The study also urges investment managers to more actively manage their portfolios through rebalancing strategies. The results could also encourage policymakers to continue to support sustainable financing initiatives.

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1. Introduction

In recent decades, much research has focused on sustainable and ESG-based investments. This has been driven by various factors, firstly the increasingly evident impacts of climate change, coupled with an increased focus on environmental ethics such as reducing carbon emissions, green energy and green technology, which has led to increasing attention from various stakeholders towards ESG issues (Deloitte, 2020; Indriastuti & Chariri, 2021). One of the stakeholders is the institutional investors who are taking measures to add SRI and ESG investments to their portfolio radar, accelerated by the COVID-19 pandemic, which encourages investors to do 'the right thing' (Morelli & Nesta, 2021). The capital market plays an important role in providing a variety of new investment products related to sustainable responsible investing (SRI) and ESG (Panagopoulos, 2023). ESG-based investments are expected to remain high in the future and become a driving force for market growth. PWC predicts that ESG assets under management will reach \$34 trillion, or 21.5% of all global assets, by 2026 (Almubarak et al., 2023). Meanwhile, Bloomberg estimates that ESG asset management could reach more than \$53 trillion by 2025, accounting for a third of global asset management, while remaining dominated by developed markets (Rumyantseva & Tarutko, 2022).

Current research in sustainable investing encompasses a variety of focus areas. Historically, Sharma et al. (2022) showed that research in the 1980s and 1990s was predominantly concerned with themes of

personal values such as 'sacrifice', 'morality', and 'religion'. Meanwhile, in the 2000s the focus shifted to more empirically oriented research, focusing on 'activism', 'sustainability', 'stakeholders', and 'financial performance'. This study also showed that specific themes of sustainable and ESG-based investments account for only 16 percent, while the rest is largely made up of socially responsible/ethical investments and responsible/impact investments. This decade, research on ESG-based investing has focused primarily on performance and comparing it to traditional investing.

Pedersen et al. (2021) propose a theory that demonstrates the potential costs and benefits of responsible investing to reconcile opposing views on whether ESG promotes or detracts from performance. However, numerous gaps remain. The conflicting results and measurement issues regarding performance in empirical articles have been well documented by Abhayawansa and Mooneepen (2022). The general conclusion from the empirical literature is that there is no statistical difference in risk-adjusted performance between ESG and conventional investing (Erragraguy & Revelli, 2015; Friede et al., 2015; Humphrey & Lee, 2011). Although most of the empirical literature demonstrates that there is no significant difference in returns, there is a small but persistent trend suggesting that actively managed ESG portfolios can generate additional returns (Sparkes & Cowton, 2004).

Despite a noticeable global shift towards sustainable practices, research on ESG investing in emerging markets, particularly in Asia (with the exception of Japan, South Korea, Taiwan and Singapore), remains strikingly sparse, accounting for just 5% of the literature (Sharma et al., 2022). There are only very limited studies for Indonesia so far; One of them is the study by Robiyanto et al. (2023), which compares ESG-based with conventional investments and shows that portfolios that take ESG into account can reduce investment risk. The current trend towards sustainable and ESG-based investments as well as the limited studies in Asia provide the fundamental basis for the importance of this research, namely the diversifying role of ESG investments in dynamic portfolio asset allocation and its optimal performance analysis.

The aim of this study is to comprehensively shed light on the contribution of Indonesian ESG-based equities to optimal portfolio diversification. Broadly speaking, diversification allows investors to reduce their cumulative risk by integrating financial assets with typically weak positive correlations. Possible declines in one asset category may be somewhat offset by upward movements in others (Díaz et al., 2022). This study also contributes to the existing literature by providing a systematic approach to building a dynamic portfolio, which consists of combining Indonesian ESG-based assets with other different asset classes, while taking into account active management of ESG portfolios in order to achieve a achieve optimal portfolio performance. Thus, the present study extends the previous literature by raising two general research questions. First, to what extent has ESG investing in Indonesia contributed to optimal portfolio construction? Second, does the performance of different types of asset classes improve when combined with local ESG-based assets?

To answer our research questions, we rely on daily data from six exchange-traded funds (ETFs) tied to various assets from 2018 to 2023. The use of ETFs offers several advantages, in line with Dutta et al. (2021) and Broadstock et al. (2021), while the time frame of the study was chosen to capture the instability associated with the outbreak of the COVID-19 pandemic, we divided the data from 2018 to 2023 into three time windows, namely pre-COVID-19, during COVID-19, and recovery. The ETFs in this study cover multiple asset classes. First, equities and government bonds are used as proxies for traditional investments in the equity and bond markets, respectively. Second, gold is used to represent assets traditionally considered safe havens. Thirdly, crude oil is a conventional commodity assets. Fourth, Bitcoin is considered a proxy for new trends in digital assets. Fifth, investments in the Indonesian equity market that address environmental concerns, i.e. ESG-based ETFs, represented by the ETF Sustainable and Responsible Investment-KEHATI (SRI-KEHATI). The ETF consists of the SRI KEHATI equity index, which uses the principles of sustainability, finance, good governance and environmental concerns as benchmarks. The SRI-KEHATI equity index was launched by the Indonesian Stock Exchange (IDX) in collaboration with Yayasan Keanekaragaman Hayati Indonesia (KEHATI, 2017; Kurniatama et al., 2021).

To achieve the aim of this study, our methodological approach is to examine the dynamic correlation of optimal portfolios of alternative assets under consideration when ESG-based ETFs are included. Using appropriate techniques, we examine the ability of this ETF asset to diversify and improve the performance of a cross-asset portfolio over time. The dynamic method will help us to grasp the tendency of stock fluctuations and somehow better simulate real situations according to the capital market dynamics

(Ogata, 2012; Zinecker et al., 2016). We apply portfolio rebalancing with different frequencies based on the minimum variance optimization method, which allows us to evaluate the portfolios for both risk and return during three COVID window periods. To model the conditional co-moments between each pair of asset returns, a DCC-GARCH is used as it is proven to be able to successfully estimate the time-varying covariance matrices (Filis et al., 2011) and is very useful for formulation various dynamic portfolio rebalancing scenarios (Díaz et al., 2022).

Various studies on the formation of cross-asset portfolios using a dynamic approach have been carried out before using ESG-based assets in the Indonesian capital market. These studies were mainly conducted by Robiyanto et al. (2021), which specifically examined the formation of cross-assets portfolio between ESG-based equities and gold, and Robiyanto et al. (2023), which expands on previous studies to include cryptocurrencies, gold, and bonds. However, to the best of the author's knowledge, there is no research on the paired portfolios between ESG-based ETFs (represented by ETF SRI-KEHATI) and the individual other assets, namely blue-chip domestic equity ETFs, gold and crude oil ETFs, Treasury ETFs and Bitcoin ETFs. The paired portfolio investments, which consist of only two assets, are often used in certain strategies such as hedging or pair trading. In these strategies, investors use the relationship between two specific assets to mitigate the risk or return of relative price movements. A paired portfolio compared to a broader cross-asset portfolio can provide a better understanding of asset correlation and is therefore more focused and suitable for specific trading or risk management objectives. Additionally, this research provides portfolio rebalancing exercises that allow us to gain insight into whether actively managing ESG portfolios provides better performance than passive investment in a single asset.

The study found that first, from a risk perspective, the time-varying volatilities of the individual asset are much higher than the paired asset volatilities of ESG-based ETFs (represented by ETF SRI-KEHATI) and any other asset, indicates that adding ESG-based asset can diversify and reduce investment risk. Second, from a performance perspective, the addition of ESG-based assets improves portfolio performance for almost all asset classes used in this study, especially during the COVID-19 pandemic, and suggests hedging functions of ESG-based assets to maintain optimal performance in the turbulent times. Third, the dynamic performance of each paired asset is consistent regardless of rebalancing scenarios and window times, demonstrating the robustness of the model. This study will contribute to the literature on cross-asset portfolios in terms of the importance of dynamic portfolio formulation and provide a better understanding of why investors support sustainable financing and why policymakers need to continue to facilitate and promote sustainable financing initiatives.

The following sections of this study are organized as follows: The second section provides an overview of the literature. The third section describes the data and methods used. The fourth section presents the results, followed by discussions in the fifth section. The final section presents conclusions from the overall study.

2. Literature review

Portfolio theory has undergone significant development. Historically, its development can be traced from traditional portfolio theory (TPT) to postmodern portfolio theory (PMPT), with modern portfolio theory (MPT) serving as a crucial milestone (Leković, 2021). TPT focuses on analyzing individual securities with a more subjective and non-systematic approach, making it less efficient at optimizing returns and risks. MPT, developed based on the pioneering ideas of individuals such as Fama (1996) and Hakansson (1975), offers a more analytical and systematic approach. MPT emphasizes the importance of diversification and interaction between assets within a portfolio and aims to achieve the maximum expected return for any given level of risk (risk-adjusted return). This theory views the portfolio as a holistic entity and not just a collection of individual securities (Shefrin & Statman, 2000).

A portfolio includes a variety of asset types or financial instruments that are used to diversify risk by dividing investments across a number of instruments (Sinchukov, 2022). At its core, diversification aims to minimize risk in order to achieve optimal returns (Pourbabaee et al., 2016). Asset allocation is about distributing investments across different asset classes, such as equities, bonds, and commodities that make up the portfolio (Bresnan & Gelb, 1999). Asset allocation, a cornerstone of portfolio management, navigates the complex landscape of financial markets using various methods (Manurung, 2016). Strategic

asset allocation, based on a buy-and-hold philosophy, formulates asset proportions based on long-term return expectations and risk tolerance, often based on fundamental analysis, and periodically rebalances these fixed proportions (Diris et al., 2015). When transitioning to tactical asset allocation, this approach provides flexibility by allowing temporary deviations from strategic allocation to optimize returns by exploiting short-term market opportunities while remaining within investment guidelines (Faber, 2017). At the same time, dynamic asset allocation, often driven by algorithmic models, continuously adapts to market trends and seeks to maximize the value of positive market changes and mitigate negative impacts through precise, timely asset reallocations, with the aim of improving risk-adjusted returns (Chang et al., 2017). Portfolios constructed using different asset allocation strategies need to be rebalanced regularly to maintain their desired target performance (Boyante et al., 2022).

A portfolio's expected return is calculated as a weighted average of each stock's expected return, adjusted for risk or fluctuations. A notable advantage of the MPT approach and its derivatives is their ability to design a portfolio with less risk than the total risk of the individual securities within it, thereby creating an optimal portfolio. Diversifying the assets in a portfolio should at least reduce risk or increase performance. Risk-adjusted return metrics are typically measured using Treynor, Sharpe, and Alpha Jensen metrics (Manurung, 2016). According to the theory of risk-adjusted returns, ESG-based investments can theoretically reduce risk by maximizing returns and thus act as diversification investments (Giese et al., 2019). Integrating ESG aspects into portfolio management has attracted considerable attention due to its potential impact on returns and risk reduction.

Today, there are only a limited number of studies that provide empirical evidence on the diversifying properties of ESG-based assets. Arif et al. (2021) have uncovered a weak dynamic link between green and conventional stock indices over time, implying diversification opportunities for investors who prioritize long-term investment horizons, particularly using data from developed countries. These results support both Breitung and Breitung and Candelon (2006) and Sharma et al. (2022) confirmed evidence of bidirectional causality between sustainable and conventional indices in the short run, but did not observe the same in the long run, with the econometric analysis firmly based on data from developed nations. In other words, Ferrer et al. (2021) have shown that strategies combining clean energy stock indices and general stocks offer no diversification or hedging benefits, while clean energy stock and green bond could offer interesting diversification prospects, all underscored by data from advanced economies.

Moreover, Yousaf et al. (2022) were unable to identify robust empirical evidence across various quantiles, designed to record extreme downturns in the S&P 500, to validate the safe-haven characteristic of clean energy stocks, even when they are integrated with positions in the S&P 500, underscoring the utilization of data derived exclusively from developed countries. Meanwhile, Díaz et al. (2022) concluded that SRI-based assets play a role in diversifying and improving the financial performance of investment portfolios with dynamic asset allocation strategies and certain rebalancing scenarios, especially when combined with different asset classes such as conventional equities, government bonds, gold, crude oil, and Bitcoin.

Overall, the literature review showed that there is a paucity of research examining the contribution of ESG investments in generating dynamic, optimal investment portfolio diversification, especially during the COVID-19 pandemic in Asian contexts, particularly in Indonesia.

3. Data and methodology

3.1. Data

The full data sample for each ETF asset consists of time series data with approximately +/- 1300 observations from January 2018 to December 2023. The data was obtained from relevant market authorities, and it is available on the Bloomberg and Refinitiv Eikon Terminals, with all necessary rights and permissions duly secured for its use. The daily close price data is first transformed into log-returns using the following formula:

$$r_t = 252 * \log \left(\frac{X_t}{X_{t-1}} \right) \quad (1)$$

Table 1. Data.

No	ETF	Ticker	Asset class	Proxy	Exposure
1	Premier ETF SRI-KEHATI	XISR.JK	Equity	ESG Equity	<i>Local</i>
2	Premier ETF LQ-45	R-LQ45X.JK	Equity	Bluechip Equity	<i>Local</i>
3	SPDR Gold Trust	GLD	Commodity	Gold	<i>Global</i>
4	United States Crude Oil ETF	USO	Commodity	Crude oil	<i>Global</i>
5	SPDR Bloomberg Barclays International Treasury Bond ETF	BWX	Bond	Government Bond	<i>Global</i>
6	Grayscale Bitcoin Trust	GBTC	Cryptocurrency	Bitcoin	<i>Global</i>

This table reports ETF data across various asset classes, including equities, commodities, bonds, and bitcoin. It details each ETF's name, ticker symbol, asset class, proxy, and geographic exposure. Data Source: Bloomberg and Refinitiv Eikon.

where r_t represents the annualized log-return for all analyzed variables, X_t is the price index at period t , and X_{t-1} denotes the price index from one day before. Local ETF data was converted into the same currency unit (US dollar). The detailed data used in the analysis are available in [Table 1](#).

An ETF is a type of mutual fund that trades on exchanges, similar to a stock, and is designed to track an index, commodity, or compilation of assets, thereby providing broad investment exposure, typically with lower fees and better liquidity, thus enabling investors to purchase or sell shares throughout the trading day at market prices. In this study, both local and global ETFs are used, first, equities and Treasury bonds as a proxy for conventional investments in the equity and fixed-income markets i.e. blue-chip equity represented by ETF LQ45 and bond ETF (SPDR Bloomberg Barclays International Treasury Bonds ETF). Second, gold (SPDR Gold Trust ETF) is used to represent assets traditionally considered safe havens. Third, crude oil (United States Crude Oil ETF) represents conventional commodity assets. Fourth, Bitcoin (Grayscale Bitcoin Trust ETF) is considered a proxy for new trends in digital assets which is both risky and contemporary (Abdullah et al., 2022). Fifth, investment in the local equity market that include environmental concerns, are represented by the SRI-KEHATI ETF.

3.2. Methodology

A four-step process is prepared to determine the contribution of ESG investments in achieving optimal investment portfolio diversification, especially during the COVID-19 pandemic in Indonesia. First, we estimate three COVID-19 window periods using the Pruned Exact Linear Time (PELT) algorithm. Second, we calculate the various conditional volatilities, the conditional covariance matrix, and the conditional correlations for the entire sample period using the DCC-GARCH model. Third, we estimate the dynamic portfolio weights that minimize the variance of the respective portfolios from each asset type and the ESG asset using a quadratic programming optimization. Fourth, we measure the portfolio returns of three COVID-19 window periods using the Sharpe ratio. To increase robustness, several rebalancing scenarios are considered.

3.2.1. Change points detection

This research uses three different time periods: pre-COVID-19, COVID-19, and the recovery period of COVID-19. To distinguish these periods, we use the PELT algorithm developed by Killick et al. (2012). This algorithm efficiently detects change points in the variance of daily returns with a linear computational cost (see [Appendix A](#)). Based on the detection of these change points, three time windows were determined. The pre-COVID-19 period extends from January 1, 2018 to February 26, 2020. The COVID-19 period begins on February 27, 2020 and ends on February 3, 2021. Meanwhile, the recovery period begins on February 4, 2021 to December 31, 2023. See [Figure 1](#) for more details on selecting these time slots.

3.2.2. Conditional volatilities, conditional covariance matrix, and conditional correlations

The next step is to calculate the optimal asset allocation to put together the portfolio. One way to maximize returns while minimizing risk is through optimal asset allocation. This becomes increasingly relevant as we consider sustainable investing trends, such as portfolios focused on ESG-based equities. To address this complexity, this research utilizes the DCC-GARCH (Dynamic Conditional Correlation

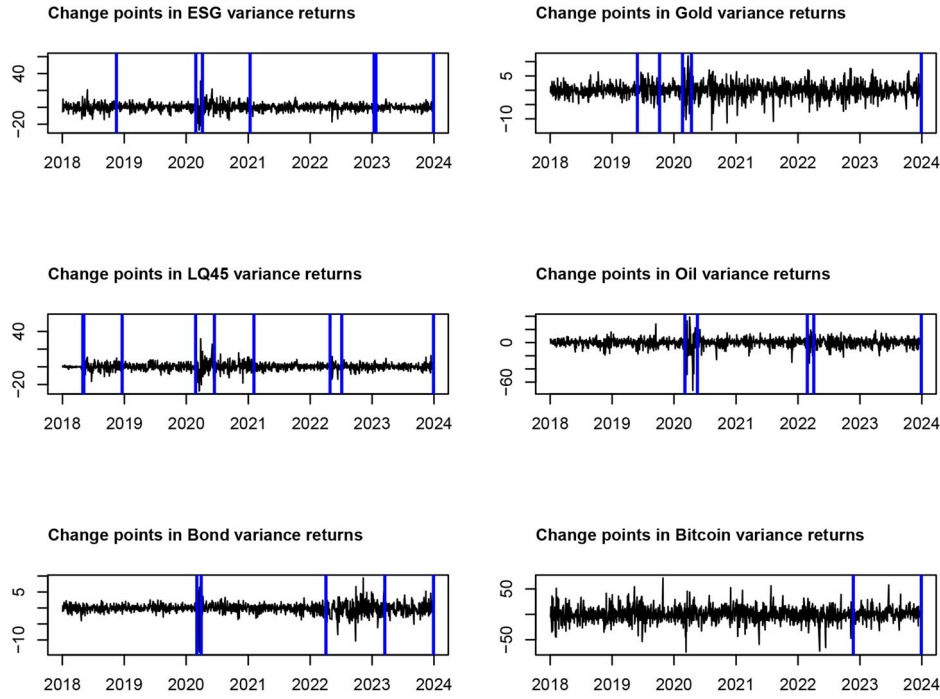


Figure 1. Changepoints on all assets.

Source: Author calculations.

This figure presents the changepoints of variance on all ETF assets based on the PELT algorithm. The determination of the research time window is subjectively based on the ESG and LQ45 assets due to their exhibiting similar patterns of change.

Generalized Autoregressive Conditional Heteroscedasticity) model and quadratic programming to create a dynamic optimal portfolio. DCC-GARCH, as an extension of the GARCH model, enables multivariate analysis and is extremely useful in capturing correlated movements between different types of assets, such as ESG, with other assets like gold, crude oil, or even Bitcoin. This model allows us to calculate the conditional covariance matrix, which is a crucial input in quadratic programming to obtain optimal asset allocation. This model allows us to calculate the conditional covariance matrix, which is a crucial input in quadratic programming to achieve optimal asset allocation. This is crucial because the ideal asset allocation continually changes according to market dynamics captured by the DCC-GARCH model (Orskaug, 2009).

The basis for the formation of the DCC-GARCH model is GARCH itself, and the GJR-GARCH model was selected in this study. The GJR-GARCH model was developed by Glosten et al. (1993). The GJR-GARCH model is able to take into account asymmetric effects or leverage effects (situations in which volatility tends to be higher when asset prices are falling than when they are rising). The following is the conditional variance model of GJR-GARCH:

$$\sigma_t^2 = \omega + \sum_{j=1}^q \alpha_j \varepsilon_{t-j}^2 + \sum_{j=1}^p \beta_j \sigma_{t-j}^2 + \sum_{j=1}^q \gamma S_{t-j}^- \varepsilon_{t-j}^2 \quad (2)$$

where S_{t-j}^- is a dummy variable that takes the value of 1 when ε_{t-j} is negative and 0 when ε_{t-j} is positive. The model states that positive volatility ($\varepsilon_t > 0$) and negative volatility ($\varepsilon_t < 0$) have different effects on conditional variance. The leverage effect is detected in the model when γ is positive (Ngunyi et al., 2019). The specification of GJR-GARCH in this study is the standard GJR-GARCH (1,1), which provides computational efficiency and ease of interpretation while capturing the key features of asset return dynamics (Díaz et al., 2022).

The conditional covariance matrix is calculated from the DCC-GARCH model. Engle (2002) and Orskaug (2009) state that the DCC-GARCH model is derived from the following equations:

$$r_t = \mu_t + \varepsilon_t \quad (3)$$

where $\varepsilon_t = H_t^{1/2} z_t$

$r_t = n \times 1$ matrix of returns from n variables used

$\mu = n \times 1$ matrix of expected values from r

$\varepsilon = n \times 1$ matrix of time-varying residuals

$H = n \times n$ matrix of conditional covariance of ε

$z = n \times 1$ matrix of residuals distributed normally with a mean of zero and constant variance

The equation $r_t = \mu_t + \varepsilon_t$ represents the mean equation of the DCC-GARCH model. The residual consists of conditional covariance (H_t) and residuals with a zero mean and constant variance (z_t). Conditional covariance is also illustrated in the following equation. This equation includes the conditional standard deviation (volatilities) and the conditional correlation of standardized residuals that change over time.

$$H_t = D_t R_t D_t$$

$$\text{where } D_t = \text{diag}\{\sigma_{i,t}\} = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{i,t} \end{bmatrix} \quad (4)$$

Note: $H_t = n \times n$ matrix of conditional covariance at time t $D_t = n \times n$ matrix of conditional standard deviation at time t $R_t = n \times n$ matrix of conditional correlation at time t .

3.2.3. The dynamic optimal weight of assets

To obtain the optimal asset allocation (dynamic optimal weights) with optimal returns at a tolerable level of risk for the best combination of the ESG portfolio with other assets, quadratic programming can be used. This is achieved by minimizing portfolio variance (Díaz et al., 2022; Manurung et al., 2021; Sahamkhadam et al., 2018).

$$\min_{w_t} (\sigma_{p,t}^2) = w_t' H_t w_t$$

$$\text{constraint: } \sum_{i=1}^n w_{it} = 1 \quad (5)$$

where H_t represents the conditional covariance matrix of dimensions $n \times n$ and w_t is the vector of dynamic optimal portfolio weights over time. The weights are subject to non-negativity constraints ($w_{1t}, w_{2t}, \dots, w_{it} \geq 0$). The optimal weights obtained are dynamic, that is, they are optimal at time t due to the presence of a conditional covariance up to t .

3.2.4. Portfolio returns and performance measure

The performance of each portfolio combination formed is then evaluated using the Sharpe Ratio, a metric that allows us to evaluate risk-adjusted returns (Sharpe, 1994):

$$SR_{(r_p)} = \frac{E_{(r_p)} - rf}{\sigma_{(r_p)}} \quad (6)$$

where $E_{(r_p)}$ and $\sigma_{(r_p)}$ are the mean and standard deviation of the portfolio returns in the period under consideration. rf is the risk-free interest rate, which is obtained from the BI 7-day reverse repo rate retrieved from Bank Indonesia (central bank) website.

This study also includes additional transaction scenarios to test the robustness of the research model. The scenarios are created whereby an investor changes the proportion or weight of each asset in the

portfolio over different time intervals (rebalancing scenarios). Portfolio rebalancing scenarios are categorized into three scenarios: daily, weekly and monthly. With daily rebalancing, the weighting of each asset changes every day. With weekly rebalancing, the weight of each asset changes every 5 days. With monthly rebalancing, the weight of each asset changes every 22 days. Optimal weights are derived from the previous procedure, which includes quadratic optimization and DCC-GARCH. The daily optimal weights use the weights of that particular day, while the weights for every 5th and 22nd days use the weights from the end of the respective period.

4. Results

4.1. Descriptive analysis

All assets experienced fluctuations during the research period, with the greatest momentum occurring in 2020. This year, almost all asset classes experienced simultaneous declines in daily closing prices, possibly due to the uncertainty created by the impact of the COVID-19 pandemic on global markets. However, there are some notable features worth highlighting. First, gold appeared particularly resilient during this period, showing a tendency to rise even in unstable market conditions. This strengthens its reputation as a 'safe haven' that typically attracts investors in times of crisis. Secondly, government bonds remained stable throughout the period, confirming their position as the lowest risk investment. Additionally, there was exceptionally high volatility in crude oil and Bitcoin. At the time, crude oil was severely affected by a sharp drop in demand and oversupply, while Bitcoin, a risky asset, offered high returns despite extreme volatility (see Figure 2).

In Table 2, we present a summary of annualized log returns for six different ETF asset classes. Gold had the highest average daily return over the sample period and Bitcoin had the highest volatility, largely due to the sharp price fluctuations in 2021. As expected, government bonds and gold showed the lowest volatility. Half of the assets recorded negative average returns, consistent with the sudden price drops in early 2020 due to COVID-19. ESG-based equities ranked with the third highest average

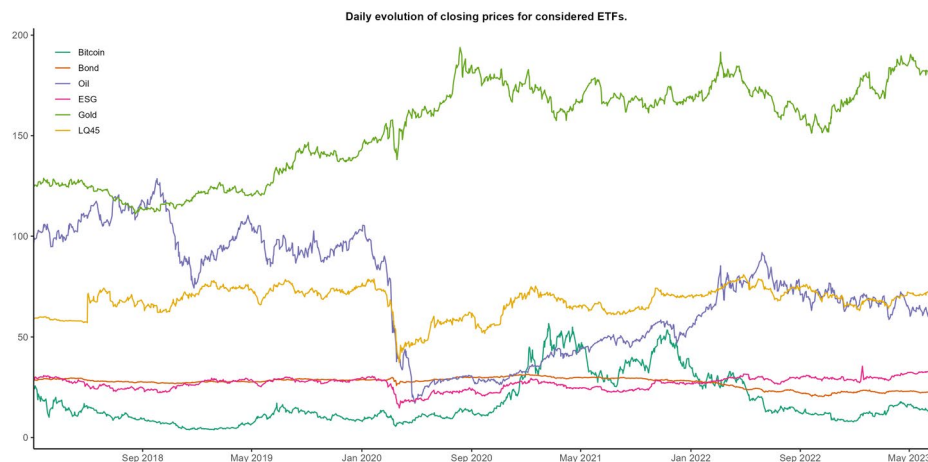


Figure 2. Daily movements of the closing price for considered ETFs.

Source: Author calculations.

This figure reports on the daily closing prices of the different ETF types under study. All price data are expressed in US dollars.

Table 2. Descriptive analysis of log returns.

	ESG	LQ45	Gold	Crude Oil	Bond	Bitcoin
Mean	0.018	0.038	0.075	−0.087	−0.054	−0.046
Std.Dev.	4.945	4.570	2.480	7.600	1.557	14.795
Min	−26.914	−27.349	−13.908	−73.557	−13.753	−73.964
Max	60.693	56.251	11.942	38.846	9.365	71.454
ADF Test	0.000	0.000	0.000	0.000	0.000	0.000

Source: Author calculations.

This table provides information on the main descriptive statistics of the log returns for ESG-based equities, LQ45, gold, crude oil, government bonds, and bitcoin. The average return (Mean), the standard deviation (Std. Dev.), and the minimum and maximum value of the series are presented in annualized terms. The ADF test provides the p-value for testing stationarity using the augmented Dickey-Fuller test.

return with relatively low risk exposure. However, its potential as an alternative diversification asset is not yet apparent. The p-value of the ADF statistic below 0.05 indicates that the data is stationary enough for DCC-GARCH analysis at the 5% significance level.

4.2. Conditional volatilities dan conditional correlations

Calculating conditional volatilities and conditional correlations can provide insight into the potential for constructing optimal asset allocations for the various asset classes selected in the study. An optimal asset combination is typically created by combining high and low asset volatility with low correlation [Figure 3](#) shows the conditional volatilities of different types of ETF assets from 2018 to 2023 resulting from the GJR-GARCH (1,1) model. Before the pandemic, most assets showed relatively stable volatility, with notable exceptions being the significant rise in Bitcoin and crude oil in mid-2019. The declaration of a pandemic by the WHO in March 2020 triggered a spike in volatility across all asset classes, including those that were traditionally more stable asset classes such as gold and government bonds. After May 2020, volatility in financial markets began to recover to pre-pandemic levels, but certain volatility spikes continued to occur, particularly in Bitcoin and crude oil.

[Table 3](#) presents a descriptive analysis showing significant differences in conditional volatility across asset types across the sample period. Bitcoin is the asset with the highest average volatility, indicating that it is the riskiest asset. In contrast, government bonds have the lowest average. ESG-based equities have a moderate risk profile as they have lower volatility than crude oil and Bitcoin, but higher volatility than treasuries and gold. However, ESG-based stocks have relatively higher volatility than LQ45.

Multivariate analysis using the DCC-GARCH model shows the conditional correlation between ESG-based equities and other assets. The conditional correlations are shown in [Figure 4](#) and their descriptive statistics are shown in [Table 4](#). Over time, ESG-based equities have exhibited a predominantly strong positive correlation with LQ45, peaking in mid-2020 during the heightened uncertainty caused by the COVID-19 outbreak. The correlation then weakens but continues to fluctuate. Meanwhile, correlations

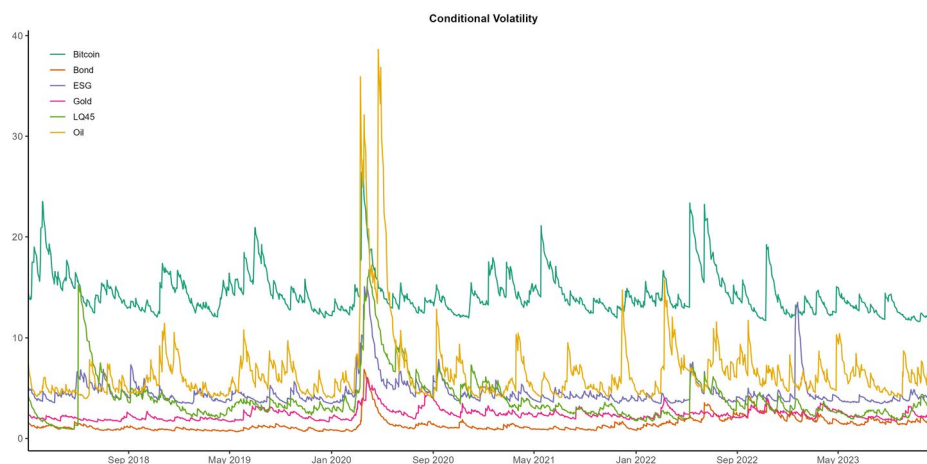


Figure 3. Daily movements of conditional volatility for considered ETFs.

Source: Author calculations.

This figure reports the conditional volatilities obtained from modelling the marginal distributions of the different assets via GARCH specifications. All considered patterns are expressed in annual terms.

Table 3. Descriptive analysis of conditional volatilities.

	ESG	LQ45	Gold	Crude Oil	Bond	Bitcoin
Mean	4.522	3.827	2.395	6.563	1.425	14.322
Std.Dev.	1.418	2.260	0.573	3.781	0.748	2.120
Min	3.447	0.915	1.658	3.966	0.669	11.620
Max	15.151	16.782	6.023	38.625	6.864	26.434

Source: Author calculations.

The table reports the key descriptive statistics of conditional volatilities for ESG-based equities, LQ45, gold, crude oil, government bonds, and bitcoin.

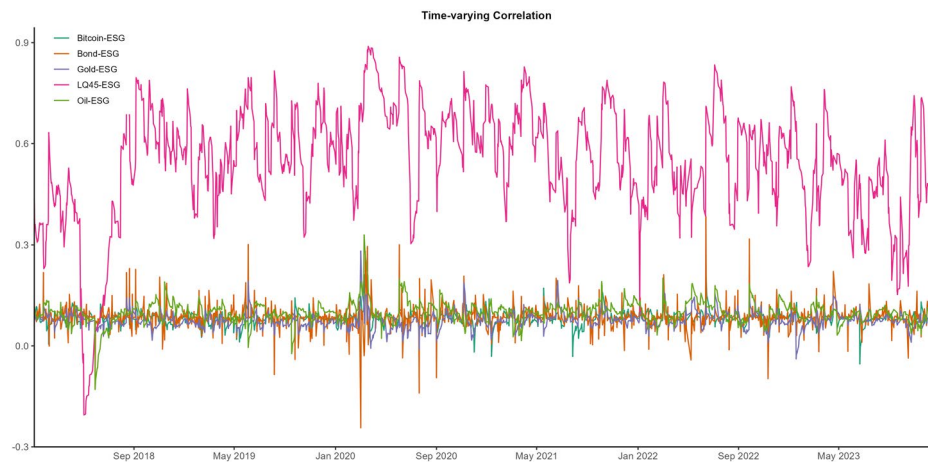


Figure 4. Daily movements of conditional correlation for considered ETFs.

Source: Author calculations.

This figure presents the conditional correlation resulting from the DCC-GARCH estimations.

Table 4. Descriptive analysis of conditional correlations.

	ESG-LQ45	ESG-Gold	ESG-Oil	ESG-Bond	ESG-Bitcoin
Mean	0.548	0.075	0.099	0.086	0.082
Std.Dev.	0.168	0.025	0.033	0.037	0.021
Min	-0.205	-0.039	-0.13	-0.243	-0.054
Max	0.889	0.282	0.329	0.384	0.247

Source: Author calculations.

This table reports on the summary statistics of the conditional correlations among the paired assets: ESG-based equities and LQ45, ESG-based equities and gold, ESG-based equities and crude oil, ESG-based equities and government bonds, and ESG-based equities and bitcoin.

between ESG-based equities and non-equity investments remain very low and move erratically over this period.

ESG-based equities have a particularly strong correlation with LQ45 but have very low correlation with other assets. The standard deviation of the correlation between ESG-based equities and LQ45 is the highest, indicating significant potential co-movement of fluctuations. The fact that ESG-based stocks have a low correlation with other assets points to their potential role as a diversification asset within investment portfolios.

4.3. The dynamic optimal weight of assets

As described in the methodology section, we divide the sample into three window periods, namely pre-COVID-19, COVID-19 and recovery. We also integrate three different portfolio rebalancing scenarios: daily (every trading day), weekly (every 5 trading days) and monthly (every 22 trading days). For daily rebalancing, portfolio weights are recalibrated every trading day, accumulating +/-1300 minimum variance optimizations. Meanwhile, the weekly and monthly rebalancing strategies have accumulated +/-260 and +/-60 minimum variance optimizations, respectively.

Table 5 provides comprehensive summary statistics of the dynamic rebalancing of various portfolio weights. Each panel provides data on the different rebalancing scenarios of each asset class pair. On average, the three portfolio rebalancing scenarios in all different time periods show that there are no obvious differences between all rebalancing scenarios. These results ensure the robustness of the research model. In the pre-COVID-19 period, portfolio allocation ratios between ESG-based equities and other asset classes showed that the average weighting of ESG-based equities was generally lower than that of LQ45 equity, gold and treasuries, but higher than that of crude oil and Bitcoin. During the COVID-19 period, the average weighting of ESG-based stocks increases and dominates the portfolio at LQ45, while gold, oil and bonds show a slight increase, with the exception of Bitcoin, which decreases slightly. As we entered the recovery phase, the average weighting of ESG-based equities for LQ45 portfolios fell

Table 5. Summary of the dynamic optimal weights.

	1Day Rebalance						5Day Rebalance						22Day Rebalance					
	Pre-COVID-19			COVID -19			Pre-COVID -19			COVID-19			Pre-COVID-19			COVID-19		
	ESG	LQ45	Recovery	ESG	LQ45	Recovery	ESG	LQ45	Recovery	ESG	LQ45	Recovery	ESG	LQ45	Recovery	ESG	LQ45	Recovery
Mean	0.270	0.730	0.619	0.381	0.252	0.748	0.258	0.742	0.615	0.385	0.254	0.746	0.251	0.749	0.544	0.456	0.243	0.757
Min	0.005	0.154	0.005	0.005	0.005	0.005	0.005	0.154	0.005	0.005	0.005	0.111	0.005	0.240	0.005	0.005	0.005	0.263
Max	0.846	0.995	0.995	0.995	0.995	0.995	0.846	0.995	0.995	0.995	0.889	0.995	0.760	0.995	0.995	0.995	0.737	0.995
	ESG	Gold	ESG	Gold	ESG	Gold	ESG	Gold	ESG	Gold	ESG	Gold	ESG	Gold	ESG	Gold	ESG	Gold
Mean	0.179	0.821	0.218	0.782	0.240	0.760	0.180	0.820	0.221	0.779	0.242	0.758	0.174	0.826	0.205	0.795	0.239	0.761
Min	0.041	0.575	0.028	0.492	0.035	0.495	0.071	0.582	0.028	0.518	0.041	0.528	0.071	0.638	0.098	0.708	0.118	0.598
Max	0.425	0.959	0.508	0.972	0.505	0.965	0.418	0.929	0.482	0.972	0.472	0.959	0.362	0.929	0.292	0.902	0.402	0.882
	ESG	Oil	ESG	Oil	ESG	Oil	ESG	Oil	ESG	Oil	ESG	Oil	ESG	Oil	ESG	Oil	ESG	Oil
Mean	0.622	0.378	0.655	0.345	0.682	0.318	0.622	0.378	0.652	0.348	0.681	0.319	0.627	0.373	0.641	0.359	0.701	0.299
Min	0.241	0.085	0.288	0.001	0.098	0.028	0.301	0.118	0.375	0.028	0.135	0.068	0.281	0.118	0.428	0.131	0.458	0.088
Max	0.915	0.759	0.999	0.712	0.972	0.902	0.882	0.699	0.972	0.625	0.932	0.865	0.882	0.719	0.869	0.572	0.912	0.542
	ESG	Bond	ESG	Bond	ESG	Bond	ESG	Bond	ESG	Bond	ESG	Bond	ESG	Bond	ESG	Bond	ESG	Bond
Mean	0.035	0.965	0.054	0.946	0.129	0.871	0.036	0.964	0.057	0.943	0.130	0.870	0.034	0.966	0.051	0.949	0.128	0.872
Min	0.002	0.868	0.002	0.798	0.008	0.542	0.002	0.892	0.015	0.848	0.015	0.542	0.002	0.932	0.002	0.885	0.022	0.645
Max	0.132	0.998	0.202	0.998	0.458	0.992	0.108	0.998	0.152	0.985	0.458	0.985	0.068	0.998	0.115	0.998	0.355	0.978
	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin	ESG	Bitcoin
Mean	0.934	0.066	0.884	0.116	0.931	0.069	0.935	0.065	0.884	0.116	0.932	0.068	0.933	0.067	0.881	0.119	0.935	0.065
Min	0.805	0.012	0.655	0.035	0.482	0.005	0.831	0.019	0.658	0.042	0.545	0.009	0.851	0.022	0.765	0.059	0.871	0.032
Max	0.988	0.195	0.965	0.345	0.995	0.518	0.981	0.169	0.958	0.342	0.991	0.455	0.978	0.149	0.941	0.235	0.968	0.129

Source: Author calculations.

This table reports on the summary statistics of the dynamic optimal weights for minimum variance portfolios of combining ESG-based equities and LQ45, ESG-based equities and gold, ESG-based equities and crude oil, ESG-based equities and government bonds, and ESG-based equities and bitcoin on each window time of the study as well as for the 1, 5, and 22-day rebalancing scenarios.



Figure 5. Portfolio weights 1-day rebalance scenario.

Source: Author calculations.

This figure presents the weight evolution for minimum variance portfolios constructed by combining the ETFs of each asset class and the ETF of ESG-based equities over the study periods for the 1-day rebalance under constrained portfolios.

significantly and returned to around pre-COVID-19 levels, although gold, oil, bonds and Bitcoin saw modest increases in allocations relative to pandemic period.

Figure 5 shows the dynamics of weighting in the minimum variance portfolio created by combining ESG-based equities with LQ45, ESG-based equities with gold, ESG-based equities with crude oil, ESG-based equities with government bonds, and ESG-based equities with Bitcoin across the entire sample for the daily rebalancing portfolio. The lowest weight for ESG-based equities are assigned to the least risky assets, namely government bonds and gold, with ESG-based equities not necessarily contributing to risk reduction but rather to improving the risk-return ratio of the overall portfolio. The very high weight of ESG-based equities is evident in portfolios with Bitcoin and crude oil, where ESG-based equities play a crucial role in reducing portfolio risk. The low weight of ESG-based equities in the portfolio with gold and government bonds, on the contrary, the very high weight of ESG-based equities in the portfolio with Bitcoin are quite stable over time. Meanwhile, the weight composition of ESG-based equities is observed to be the most unstable with crude oil and LQ45 portfolios. When applied to the 5-day and 22-day rebalancing scenarios, as shown in Figures 6 and 7 respectively, the dynamic weight changes of each portfolio show only slightly different movements, supporting the robustness of the results.



Figure 6. Portfolio weights 5-day rebalance scenario.

Source: Author calculations.

This figure presents the weight evolution for minimum variance portfolios constructed by combining the ETFs of each asset class and the ETF of ESG-based equities over the study periods for the 5-day rebalance under constrained portfolios.

4.4. Portfolio returns and performance

The performance measurement simulation in this study follows a dynamic asset allocation strategy in which the weight of each asset actively fluctuates. The evaluation spans three time windows based on the COVID-19 period and takes into account three rebalancing scenarios, providing a wide range of information for various investment decisions. The Sharpe ratio is used as a measure for performance evaluation, with the optimal portfolio being identified as the one with the highest risk-adjusted return.

Table 6 shows the portfolio performance evaluation with daily rebalancing scenario. In the pre-pandemic period, only LQ45 and gold showed solid performance with positive risk-adjusted returns compared to others. When we combine ESG-based equities with LQ45, the portfolio generates a 4.2 percentage point higher risk-adjusted return. In contrast, combining ESG-based equities with gold resulted in a 2.2 percentage point decrease in risk-adjusted returns. For other assets, the impact of including ESG-based equities was not significantly apparent, although it reduced the risk associated with crude oil and Bitcoin assets.

There has been significant turbulence in global markets during the pandemic. Individual assets such as gold and government bonds served as safe havens, offering protection with positive risk-adjusted

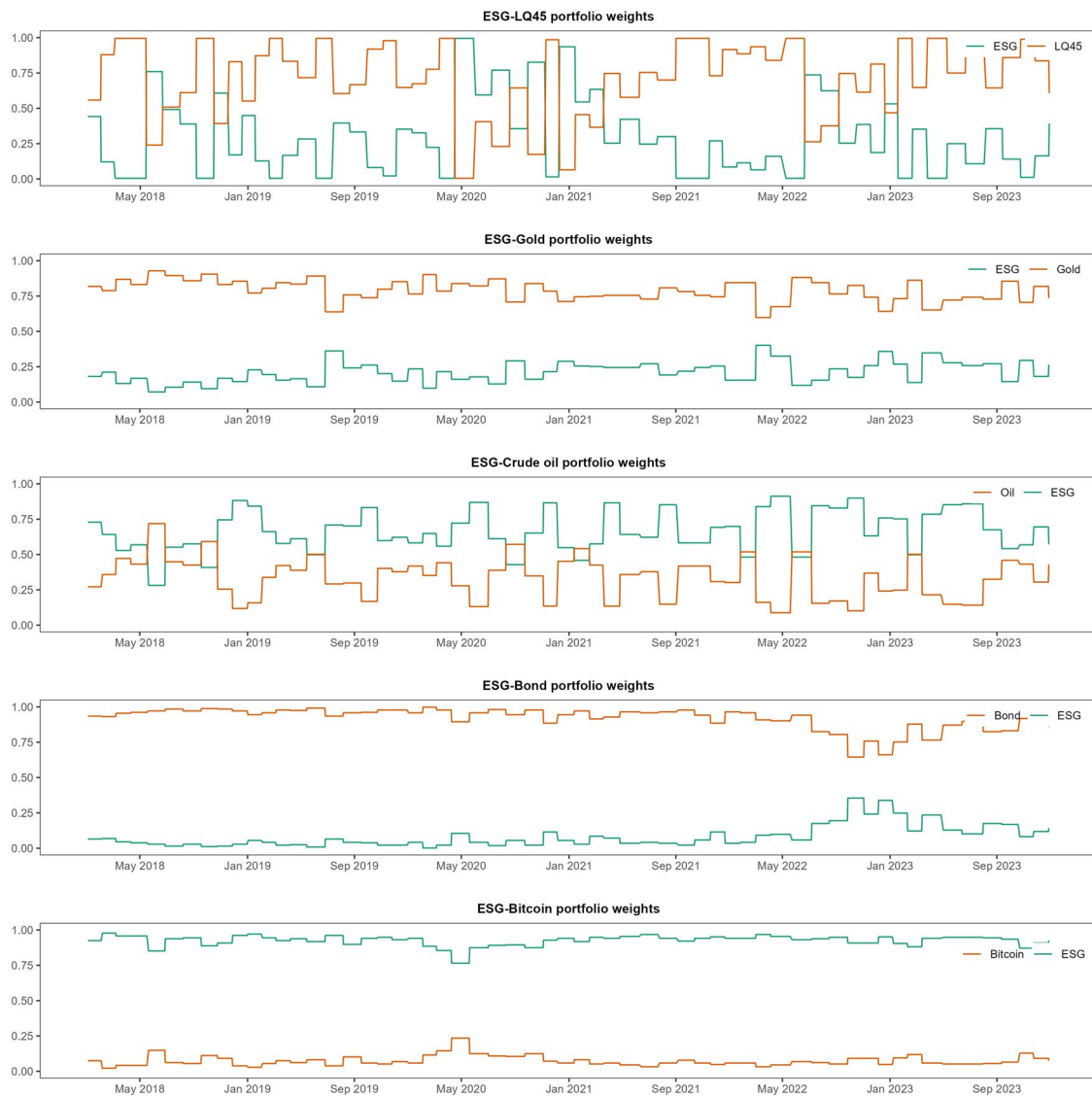


Figure 7. Portfolio weights 22-day rebalance scenario.

Source: Author calculations.

This figure presents the weight evolution for minimum variance portfolios constructed by combining the ETFs of each asset class and the ETF of ESG-based equities over the study periods for the 22-day rebalance under constrained portfolios.

returns. When we combine ESG-based equities with gold, we see an increase in risk-adjusted return 3.1 percentage points higher than just holding gold, and when we combine ESG-based equities with government bonds, the risk-adjusted return increases by 5.7 Percentage points higher than simply holding gold government bonds. This points to the potential role of ESG-based equities in improving the portfolio performance of the less risky assets. Investing in Bitcoin generates the highest risk-adjusted return among individual asset classes, but its performance deteriorates slightly when assembled as a portfolio of ESG-based equities. In this portfolio, ESG-based equities still have a dominant weight (more than 80%), which means that ESG-based equities not only help to hedge and mitigate the risks of investing in Bitcoin, but also somewhat preserves its performance value. In the case of oil, the individual investment produces a negative result. However, when combined with ESG-based equities, the portfolio has a positive risk-adjusted return, indicating the ability of ESG-based equities to absorb risks arising from the increased uncertainty in the commodity market during the pandemic.

Throughout the recovery period, only gold and crude oil investments generate a positive risk-adjusted return. However, when ESG-based equities are included in both gold and crude oil, there are only minor changes in the risk-adjusted return. The combination of ESG-based equities with LQ45 and ESG-based

Table 6. Summary of the 1-day portfolio rebalancing scenario performance.

	Pre-COVID-19		COVID –19		Recovery	
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	0.080	0.074	0.034	–0.127	–0.003	0.013
Std.Dev	4.100	4.025	7.593	7.516	3.072	2.973
Sharpe	0.016	0.058	0.002	–0.002	–0.006	–0.008
	Gold	ESG + Gold	Gold	ESG + Gold	Gold	ESG + Gold
Mean	0.109	0.068	0.141	0.194	0.045	0.056
Std.Dev	1.845	1.635	3.530	3.212	2.455	2.237
Sharpe	0.051	0.029	0.035	0.066	0.012	0.012
	Oil	ESG + Oil	Oil	ESG + Oil	Oil	ESG + Oil
Mean	–0.089	–0.036	–0.995	–0.293	0.241	0.114
Std.Dev	5.110	2.988	13.094	6.788	6.342	3.559
Sharpe	–0.021	–0.018	–0.077	0.011	0.035	0.028
	Bond	ESG + Bond	Bond	ESG + Bond	Bond	ESG + Bond
Mean	–0.001	–0.007	0.087	0.061	–0.115	–0.098
Std.Dev	0.886	0.875	2.072	2.180	1.796	1.719
Sharpe	–0.019	–0.017	0.034	0.091	–0.073	–0.098
	Bitcoin	ESG + Bitcoin	Bitcoin	ESG + Bitcoin	Bitcoin	ESG + Bitcoin
Mean	–0.461	–0.102	1.664	0.128	–0.040	0.090
Std.Dev	15.284	3.805	15.670	6.832	13.337	4.084
Sharpe	–0.031	–0.030	0.105	0.063	–0.004	0.019

Source: Author calculations.

This table reports on the summary statistics of the observed returns (Mean), risk (Std.Dev), and performance measure (Sharpe) for the 1-day rebalancing scenario assessment on investment for single asset: LQ45, gold, crude oil, government bonds, and bitcoin as compared to paired assets: ESG-based equities and LQ45, ESG-based equities and gold, ESG-based equities and crude oil, ESG-based equities and government bonds, and ESG-based equities and bitcoin.

Table 7. Summary of the 5-day portfolio rebalancing scenario performance.

	Pre-COVID-19		COVID –19		Recovery	
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	0.080	0.076	0.034	–0.006	–0.003	0.001
Std.Dev	4.100	4.027	7.593	7.350	3.072	2.960
Sharpe	0.016	0.065	0.002	0.018	–0.006	–0.009
	Gold	ESG + Gold	Gold	ESG + Gold	Gold	ESG + Gold
Mean	0.109	0.078	0.141	0.203	0.045	0.053
Std.Dev	1.845	1.646	3.530	3.264	2.455	2.240
Sharpe	0.051	0.034	0.035	0.071	0.012	0.011
	Oil	ESG + Oil	Oil	ESG + Oil	Oil	ESG + Oil
Mean	–0.089	–0.019	–0.995	–0.164	0.241	0.131
Std.Dev	5.110	3.020	13.094	6.922	6.342	3.646
Sharpe	–0.021	–0.014	–0.077	0.033	0.035	0.036
	Bond	ESG + Bond	Bond	ESG + Bond	Bond	ESG + Bond
Mean	–0.001	–0.004	0.087	0.096	–0.115	–0.103
Std.Dev	0.886	0.874	2.072	2.219	1.796	1.725
Sharpe	–0.019	–0.014	0.034	0.097	–0.073	–0.100
	Bitcoin	ESG + Bitcoin	Bitcoin	ESG + Bitcoin	Bitcoin	ESG + Bitcoin
Mean	–0.461	–0.084	1.664	0.153	–0.040	0.090
Std.Dev	15.284	3.807	15.670	6.992	13.337	4.072
Sharpe	–0.031	–0.026	0.105	0.067	–0.004	0.020

Source: Author calculations.

This table reports on the summary statistics of the observed returns (Mean), risk (Std.Dev), and performance measure (Sharpe) for the 5-day rebalancing scenario assessment on investment for single asset: LQ45, gold, crude oil, government bonds, and bitcoin as compared to paired assets: ESG-based equities and LQ45, ESG-based equities and gold, ESG-based equities and crude oil, ESG-based equities and government bonds, and ESG-based equities and bitcoin.

equities with government bonds performs in negative territory. On the contrary, combining ESG-based equities with Bitcoin improved the risk-adjusted return from negative to positive, thereby confirming the hedging function of ESG-based equities.

Tables 7 and 8, respectively, show the results of scenarios for 5-day and 22-day rebalancing. The performance of risk-adjusted returns for individual assets and in combination with ESG-based equities produced relatively similar results compared to the 1-day rebalancing scenario. The consistency of these results confirms the robustness of our analysis. It is important to note that we do not take transaction costs into account when comparing investment risks in 1-, 5- and 22-day rebalancing scenarios. Under normal circumstances, more frequent trading may result in higher transaction costs.

Table 8. Summary of the 22-day portfolio rebalancing scenario performance.

	Pre-COVID-19		COVID –19		Recovery	
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	0.080	0.083	0.034	0.045	–0.003	0.035
Std.Dev	4.100	4.088	7.593	7.446	3.072	3.265
Sharpe	0.016	0.066	0.002	0.017	–0.006	0.005
	Gold	ESG + Gold	Gold	ESG + Gold	Gold	ESG + Gold
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	0.109	0.074	0.141	0.130	0.045	0.052
Std.Dev	1.845	1.645	3.530	3.192	2.455	2.246
Sharpe	0.051	0.031	0.035	0.049	0.012	0.012
	Oil	ESG + Oil	Oil	ESG + Oil	Oil	ESG + Oil
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	–0.089	–0.020	–0.995	–0.267	0.241	0.114
Std.Dev	5.110	3.071	13.094	7.284	6.342	3.815
Sharpe	–0.021	–0.015	–0.077	0.031	0.035	0.037
	Bond	ESG + Bond	Bond	ESG + Bond	Bond	ESG + Bond
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	–0.001	–0.006	0.087	0.110	–0.115	–0.102
Std.Dev	0.886	0.872	2.072	2.096	1.796	1.756
Sharpe	–0.019	–0.016	0.034	0.100	–0.073	–0.097
	Bitcoin	ESG + Bitcoin	Bitcoin	ESG + Bitcoin	Bitcoin	ESG + Bitcoin
	LQ45	ESG + LQ45	LQ45	ESG + LQ45	LQ45	ESG + LQ45
Mean	–0.461	–0.109	1.664	0.218	–0.040	0.074
Std.Dev	15.284	3.795	15.670	6.977	13.337	4.141
Sharpe	–0.031	–0.031	0.105	0.076	–0.004	0.021

Source: Author calculations.

This table reports on the summary statistics of the observed returns (Mean), risk (Std.Dev), and performance measure (Sharpe) for the 22-day rebalancing scenario assessment on investment for single asset: LQ45, gold, crude oil, government bonds, and bitcoin as compared to paired assets: ESG-based equities and LQ45, ESG-based equities and gold, ESG-based equities and crude oil, ESG-based equities and government bonds, and ESG-based equities and bitcoin.

5. Discussion

This study showed how ESG investing contributes to optimal portfolio construction. First, from a risk perspective, the time-varying volatilities of any individual asset are always higher than those of paired assets of ESG-based equities and any other asset. This result suggests that the addition of ESG-based equities can diversify and reduce investment risk for conventional and safe havens, commodities and digital assets, particularly crude oil and Bitcoin. Second, from a performance perspective, the addition of ESG-based equities improves portfolio performance for most asset classes, i.e. gold, government bonds, and oil, especially during the COVID-19 pandemic. This demonstrates the diversifying role of ESG-based equities and the hedging functions of ESG-based equities to maintain optimal performance in turbulent times.

These results were consistent with Dai (2021) and Jin (2022), which stated that ESG investing can reduce risk and improve the risk-adjusted return of the overall portfolio. The result of the study also agrees with Hoepner (2010) that optimal portfolio diversification, particularly through the use of ESG-based assets, can be achieved across a variety of asset classes. A notable finding of this study highlights that a high weighting of ESG-based equities in the crude oil and Bitcoin portfolio has the potential to reduce risk and is consistent with Liu and Hamori (2020). Conversely, the relatively low weighting of ESG-based equities with assets such as bonds and gold has the potential to improve portfolio performance, although without associated risk reduction.

Overall, the empirical results of this study support the fact that, beyond diversification, the inclusion of ESG-based equities also provides insurance and improves portfolio performance. During the COVID-19 period, most asset classes used in this study performed positively and even better when each individual asset was paired with ESG-based equities, particularly gold, treasuries and oil. Moreover, a portfolio of ESG-based equities and Bitcoin generates positive risk-adjusted returns during the pandemic, although slightly lower than holding just Bitcoin. The portfolio combining ESG-based stocks with gold not only achieved a higher mean return (+5.3 percentage points) compared to a gold-only strategy, but also showed an improvement in the associated risk (–9.0 percent). In fact, a portfolio of ESG-based equities and gold achieved a 3.1 percentage point improvement in risk-adjusted returns. This is in marked contrast to the findings of Akhtaruzzaman et al. (2021) and Ji et al. (2020), which highlight gold's unwavering role as a safe haven during periods of financial instability caused by the COVID-19 pandemic, and that of Salisu et al. (2021), which underline its conditional hedging properties.

A similar observation applies to government bonds, which can be classified as less risky assets. During the pandemic, a portfolio of ESG-based equities and government bonds has similar characteristics to a portfolio of ESG-based equities and gold. Combining ESG-based equities and government bonds can increase the portfolio's risk-adjusted return by 5.7 percentage points. Despite the prevailing evidence that gold and government bonds are a relatively stable and risk-mitigating asset in turbulent times, our results show that including ESG-based equities in the investment portfolio can actually mitigate risk even further.

In times of market turmoil and the health crisis, the diversification and hedging function of ESG-based equities takes on great importance, especially with Bitcoin and crude oil. By combining Bitcoin with ESG-based equities during the COVID-19 period, the mean return decreases by 1536 percentage points compared to what we would achieve if we invested exclusively in Bitcoin, but the associated risk is reduced by 56.4 percent. Across the sample period, portfolios of ESG-based stocks and Bitcoin reduced associated risk by approximately 66.9 percent. Given the collapse in crude oil prices triggered by the coronavirus outbreak, a portfolio of ESG-based equities and crude oil was successful in mitigating the losses before and during the COVID-19 periods (37.8 percentage points) compared to a portfolio composed exclusively of crude oil in the same periods, and the associated risk was significantly reduced (50.1 percent). During the recovery period, combining crude oil with ESG-based equities continues to reduce the associated risk (43.9 percent) compared to investing in crude oil alone.

The rebalancing scenarios aimed at improving performance were supported by existing research such as Horn and Oehler (2020). The central idea behind such rebalancing is the ability to recalibrate a portfolio's asset allocation, aligning it with an investor's goals and risk tolerance while managing the dynamic nature of market conditions (Hong, 2021). This study provides a noteworthy finding on rebalancing scenarios. The performance of the risk-adjusted returns for each portfolio shows a similar result regardless of the rebalancing scenarios (daily, weekly or monthly), although a slightly better or lower value in some portfolios. Both ESG-based equities with government bonds and ESG-based equities with Bitcoin portfolios consistently experienced optimal risk-adjusted returns across all rebalancing scenarios.

While this study contributes to the cross-asset portfolio literature in terms of the importance of a dynamic portfolio and understanding rebalancing scenarios, it has limitations that must be acknowledged. First, constructing a portfolio using asset classes from different market areas may be limited by the existence of different rules and regulations. Second, differences in market areas can also impact the portfolio rebalancing process, particularly with regard to transaction costs. Third, portfolio performance is measured using only the Sharpe ratio. Therefore, providing room for further research.

6. Conclusion and remarks

The aim of this study is to examine the role of Indonesia's ESG-based equities in achieving optimal portfolio diversification and contribute to the current state of knowledge by building a dynamic portfolio consisting of combining the ESG-based equities with different asset classes. The study found that the addition of ESG-based equities can diversify and reduce investment risk. Additionally, ESG-based equities have hedging features to maintain optimal performance during turbulent times. This study expands our understanding of the importance of dynamic portfolios and actively managed portfolios.

During the COVID-19 pandemic, most asset classes used in this analysis performed positively and even performed better when each individual investment was paired with ESG-based equities, particularly gold, bonds and oil, with only Bitcoin underperforming. The results of this study reaffirmed the evidence that government bonds and gold are comparatively stable and risk-reducing investments in uncertain times. They also highlighted the fact that including ESG-based equities in investment portfolios can help reduce risk even further. The study also highlights the importance of ESG-based equities in portfolios containing riskier assets such as Bitcoin and crude oil. ESG-based equities have proven to be a reliable source of diversification and hedging in both crude oil and Bitcoin portfolios. During the observation period, ESG-based equities always had a dominant mean dynamic weight, accounting for more than 60 percent (crude oil) and 80 percent (bitcoin). This suggests that ESG-based equities

not only help reduce the risks associated with investing in Bitcoin and crude oil, but also help preserve performance. This means that Indonesia's ESG-based equities, although still at an early stage of development, are playing quite an impressive role, similar to their more mature ESG-based equities counterparts in global markets.

The study implies that investment managers and investors can reduce investment risk and balance their portfolio by including ESG-based equities in their portfolio. The study also provides a better understanding of why investors support the emergence of ESG-based assets, but challenges investment managers to firstly create more diverse ESG-based investment products and, secondly, to operate more actively managed portfolios by rebalancing their strategy needs and risk tolerance of the customer. The results could encourage policymakers to continue supporting sustainable financing initiatives. Finally, this study opens several avenues for further research, such as the use of various ESG-based assets, adding more diverse assets, incorporating transaction costs into the rebalancing strategy, and incorporating other methods of calculating performance metrics such as Treynor and Kappa, or Omega.

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Authors' contributions

Kiki Nindya Asih and Noer Azam Achsani were involved in the conception and design. Kiki Nindya Asih and Tanti Novianti were involved in the analysis and interpretation of the data, including drafting the paper. Noer Azam Achsani and Adler Haymans Manurung were involved in the critical revision of the intellectual content. All authors have given final approval to the version to be published and agree to be accountable for all aspects of the work.

Consent for publication

Not Applicable.

Ethics approval and consent to participate

Not Applicable

Geolocation information

This study was conducted at School of Business, IPB University, Bogor, Indonesia. -6.586648122212661, 106.80609973030377.

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Data availability statement

The data that support the findings of this study are openly available in Bloomberg and Refinitiv Eikon terminals (<https://www.bloomberg.com> and <https://eikon.refinitiv.com>).

References

- Abdullah, A. M., Abdul Wahab, H., Ghazali, M. F., Yaacob, M. H., & Masih, A. M. M. (2022). The dynamics of Australian stock indices and commodities based on MGARCH-DCC and wavelet techniques. *Cogent Business & Management*, 9(1), 2152154. <https://doi.org/10.1080/23311975.2022.2152154>
- Abhayawansa, S., & Mooneeapen, O. (2022). Directions for future research to steer environmental, social and governance (ESG) investing to support sustainability: A systematic literature review. In *Handbook of accounting and sustainability* (pp. 318–341). Edward Elgar Publishing.
- Akhtaruzzaman, M., Boubaker, S., Lucey, B. M., & Sensoy, A. (2021). Is gold a hedge or a safe-haven asset in the COVID–19 crisis? *Economic Modelling*, 102, 105588. <https://doi.org/10.1016/j.econmod.2021.105588>
- Almubarak, W. I., Chebbi, K., & Ammer, M. A. (2023). Unveiling the connection among ESG, earnings management, and financial distress: Insights from an emerging market. *Sustainability*, 15(16), 12348. <https://doi.org/10.3390/su151612348>
- Arif, M., Hasan, M., Alawi, S. M., & Naeem, M. A. (2021). COVID-19 and time-frequency connectedness between green and conventional financial markets. *Global Finance Journal*, 49, 100650. <https://doi.org/10.1016/j.gfj.2021.100650>
- Boyante, R., Muturi, W., & Gekara, M. (2022). Moderating influence of portfolio rebalancing on the relationship between asset allocation and financial performance of pension funds in Kenya. *International Journal of Finance and Accounting*, 7(3), 56–67. <https://doi.org/10.47604/ijfa.1644>
- Breitung, J., & Candelon, B. (2006). Testing for short- and long-run causality: A frequency-domain approach. *Journal of Econometrics*, 132(2), 363–378. <https://doi.org/10.1016/j.jeconom.2005.02.004>
- Bresnan, B., & Gelb, E. (1999). *Getting started in asset allocation*. Wiley.
- Broadstock, D. C., Chan, K., Cheng, L. T. W., & Wang, X. (2021). The role of ESG performance during times of financial crisis: Evidence from COVID-19 in China. *Finance Research Letters*, 38, 101716. <https://doi.org/10.1016/j.frl.2020.101716>
- Chang, K. C., Tian, Z., & Yu, J. (2017). *Dynamic asset allocation—Chasing a moving target* [Paper presentation]. In 2017 20th International Conference on Information Fusion (Fusion). IEEE, pp. 1–8. <https://doi.org/10.23919/ICIF.2017.8009870>
- Dai, Y. (2021). Can ESG investing beat the market and improve portfolio diversification? Evidence from China. *The Chinese Economy*, 54(4), 272–285. <https://doi.org/10.1080/10971475.2020.1857063>
- Deloitte. (2020). *ESG platforms – Stakeholder communications and the role of technology*. Retrieved 2023, Mar 25, from <https://www.processmap.com/ehs-software/esg-stakeholder-communications-and-the-role-of-technology/>.
- Díaz, A., Esparcia, C., & López, R. (2022). The diversifying role of socially responsible investments during the COVID-19 crisis: A risk management and portfolio performance analysis. *Economic Analysis and Policy*, 75, 39–60. <https://doi.org/10.1016/j.eap.2022.05.001>
- Diris, B., Palm, F., & Schotman, P. (2015). Long-Term Strategic Asset Allocation: An Out-of-Sample Evaluation. *Management Science*, 61(9), 2185–2202. <https://doi.org/10.1287/mnsc.2014.1924>

- Dutta, A., Bouri, E., Dutta, P., & Saeed, T. (2021). Commodity market risks and green investments: Evidence from India. *Journal of Cleaner Production*, 318, 128523. <https://doi.org/10.1016/j.jclepro.2021.128523>
- Engle, R. (2002). Dynamic conditional correlation. *Journal of Business & Economic Statistics*, 20(3), 339–350. <https://doi.org/10.1198/073500102288618487>
- Erragraguy, E., & Revelli, C. (2015). Should Islamic investors consider SRI criteria in their investment strategies? *Finance Research Letters*, 14, 11–19. <https://doi.org/10.1016/j.frl.2015.07.003>
- Faber, M. (2017). A quantitative approach to tactical asset allocation revisited 10 years later. *The Journal of Portfolio Management*, 44(2), 156–167. <https://doi.org/10.3905/jpm.2018.44.2.156>
- Fama, E. F. (1996). Multifactor portfolio efficiency and multifactor asset pricing. *The Journal of Financial and Quantitative Analysis*, 31(4), 441. <https://doi.org/10.2307/2331355>
- Ferrer, R., Benítez, R., & Bolós, V. J. (2021). Interdependence between green financial instruments and major conventional assets: A wavelet-based network analysis. *Mathematics*, 9(8), 900. <https://doi.org/10.3390/math9080900>
- Filis, G., Degiannakis, S., & Floros, C. (2011). Dynamic correlation between stock market and oil prices: The case of oil-importing and oil-exporting countries. *International Review of Financial Analysis*, 20(3), 152–164. <https://doi.org/10.1016/j.irfa.2011.02.014>
- Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment*, 5(4), 210–233. <https://doi.org/10.1080/20430795.2015.1118917>
- Giese, G., Lee, L.-E., Melas, D., Nagy, Z., & Nishikawa, L. (2019). Performance and risk analysis of index-based ESG portfolios. *The Journal of Index Investing*, 9(4), 46–57. <https://doi.org/10.3905/jii.2019.9.4.046>
- Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the relation between the expected value and the volatility of the nominal excess return on stocks. *The Journal of Finance*, 48(5), 1779–1801. <https://doi.org/10.1111/j.1540-6261.1993.tb05128.x>
- Hakansson, N. H. (1975). Optimal investment and consumption strategies under risk for a class of utility functions. In *Stochastic Optimization Models In Finance* (2006 Edition) (pp. 525–545). Academic Press. <https://doi.org/10.1016/B978-0-12-780850-5.50045-9>
- Hoepner, A. G. F. (2010). Corporate Social Responsibility and Investment Portfolio Diversification. *SSRN Electronic Journal*, 10, 1–16. <https://doi.org/10.2139/ssrn.1599334>
- Hong, X. (2021). Portfolio rebalancing: Tradeoffs and decisions. *SSRN Electronic Journal*, 10, 1–21. <https://doi.org/10.2139/ssrn.3858951>
- Horn, M., & Oehler, A. (2020). Automated portfolio rebalancing: Automatic erosion of investment performance? *Journal of Asset Management*, 21(6), 489–505. <https://doi.org/10.1057/s41260-020-00183-0>
- Humphrey, J. E., & Lee, D. D. (2011). Australian socially responsible funds: Performance, risk and screening intensity. *Journal of Business Ethics*, 102(4), 519–535. <https://doi.org/10.1007/s10551-011-0836-7>
- Indriastuti, M., & Chariri, A. (2021). The role of green investment and corporate social responsibility investment on sustainable performance. *Cogent Business & Management*, 8(1), 1960120. <https://doi.org/10.1080/23311975.2021.1960120>
- Ji, Q., Zhang, D., & Zhao, Y. (2020). Searching for safe-haven assets during the COVID-19 pandemic. *International Review of Financial Analysis*, 71, 101526. <https://doi.org/10.1016/j.irfa.2020.101526>
- Jin, I. (2022). Systematic ESG Risk and decision criteria for optimal portfolio selection. *The Journal of Portfolio Management*, 48(10), 206–225. <https://doi.org/10.3905/jpm.2022.1.418>
- KEHATI. (2017). Laporan Tahunan 2017.
- Killick, R., Fearnhead, P., & Eckley, I. A. (2012). Optimal detection of changepoints with a linear computational cost. *Journal of the American Statistical Association*, 107(500), 1590–1598. <https://doi.org/10.1080/01621459.2012.737745>
- Kurniatama, G. A., Robiyanto, R., Sasongko, G., & Huruta, A. D. (2021). Determinants of corporate social responsibility: Empirical evidence from sustainable and responsible investment index. *Calitatea*, 22(183), 55–61.
- Leković, M. (2021). Historical development of portfolio theory. *Tehnika*, 76(2), 220–227. <https://doi.org/10.5937/tehnik-a2102220L>
- Liu, G., & Hamori, S. (2020). Can one reinforce investments in renewable energy stock indices with the ESG index? *Energies*, 13(5), 1179. <https://doi.org/10.3390/en13051179>
- Manurung, A. H. (2016). *Konstruksi portofolio efek di Indonesia*. Adler Manurung Press.
- Manurung, A. H., Kartono, R., Tjahjana, D. D., Tjiptadi, D., & Saputra, N. (2021). *Manajemen: Teori dan Perkembangannya*. PT Adler Manurung Press.
- Morelli, A., & Nesta, A. (2021). *Reader survey, 18+ U.S. Investors*.
- Ngunyi, A., Mundia, S., & Omari, C. (2019). Modelling volatility dynamics of cryptocurrencies using GARCH models. *Journal of Mathematical Finance*, 09(04), 591–615. <https://doi.org/10.4236/jmf.2019.94030>
- Ogata, H. (2012). Optimal portfolio estimation for dependent financial returns with generalized empirical likelihood. *Advances in Decision Sciences*, 2012, 1–8. <https://doi.org/10.1155/2012/973173>
- Orskaug, E. (2009). Multivariate DCC-GARCH model: -With various error distributions.
- Panagopoulos, A. (2023). The use of sustainable financial instruments in relation to the social impact investment. ESG policies, capital markets' approach and investors' protection. an innovative perspective. *SSRN Electronic Journal*, 10, 1–66. <https://doi.org/10.2139/ssrn.4131735>

- Pedersen, L. H., Fitzgibbons, S., & Pomorski, L. (2021). Responsible investing: The ESG-efficient frontier. *Journal of Financial Economics*, 142(2), 572–597. <https://doi.org/10.1016/j.jfineco.2020.11.001>
- Pourbabaee, F., Kwak, M., & Pirvu, T. A. (2016). Risk minimization and portfolio diversification. *Quantitative Finance*, 16(9), 1325–1332. <https://doi.org/10.1080/14697688.2015.1115891>
- Robiyanto, R., Huruta, A. D., Frensidy, B., & Yuliana, A. F. (2023). Sustainable and responsible investment dynamic cross-asset portfolio. *Cogent Business & Management*, 10(1), 2174478. <https://doi.org/10.1080/23311975.2023.2174478>
- Robiyanto, R., Nugroho, B. A., Huruta, A. D., Frensidy, B., & Suyanto, S. (2021). Identifying the role of gold on sustainable investment in Indonesia: The DCC-GARCH approach. *Economies*, 9(3), 119. <https://doi.org/10.3390/economies9030119>
- Rumyantseva, A., & Tarutko, O. (2022). (2022). Impact of the ESG principles on the corporate financial strategy. In *Challenges and Solutions in the Digital Economy and Finance: Proceedings of the 5th International Scientific Conference on Digital Economy and Finances (DEFIN 2022)* (pp. 309–318). Springer.
- Sahamkhadam, M., Stephan, A., & Östermark, R. (2018). Portfolio optimization based on GARCH-EVT-Copula forecasting models. *International Journal of Forecasting*, 34(3), 497–506. <https://doi.org/10.1016/j.ijforecast.2018.02.004>
- Salisu, A. A., Raheem, I. D., & Vo, X. V. (2021). Assessing the safe haven property of the gold market during COVID-19 pandemic. *International Review of Financial Analysis*, 74, 101666. <https://doi.org/10.1016/j.irfa.2021.101666>
- Sharma, G. D., Sarker, T., Rao, A., Talan, G., & Jain, M. (2022). Revisiting conventional and green finance spillover in post-COVID world: Evidence from robust econometric models. *Global Finance Journal*, 51, 100691. <https://doi.org/10.1016/j.gfj.2021.100691>
- Sharpe, W. F. (1994). The sharpe ratio. *The Journal of Portfolio Management*, 21(1), 49–58. <https://doi.org/10.3905/jpm.1994.409501>
- Shefrin, H., & Statman, M. (2000). Behavioral portfolio theory. *The Journal of Financial and Quantitative Analysis*, 35(2), 127. <https://doi.org/10.2307/2676187>
- Sinchukov, A. (2022). General issues of designing and managing a portfolio of financial instruments. *Scientific Research and Development. Economics*, 10(1), 36–43. <https://doi.org/10.12737/2587-9111-2022-10-1-36-43>
- Sparkes, R., & Cowton, C. J. (2004). The maturing of socially responsible investment: A review of the developing link with corporate social responsibility. *Journal of Business Ethics*, 52(1), 45–57. <https://doi.org/10.1023/B:BUSI.0000033106.43260.99>
- Yousaf, I., Suleman, M. T., & Demirel, R. (2022). Green investments: A luxury good or a financial necessity? *Energy Economics*, 105, 105745. <https://doi.org/10.1016/j.eneco.2021.105745>
- Zinecker, M., Balcerzak, A. P., Faldzinski, M., Pietrzak, M. B., & Meluzin, T. (2016). *Application of DCC-GARCH model for analysis of interrelations among capital markets of Poland, Czech Republic and Germany*. Institute of Economic Research Working Papers.

Appendix A. Pruned exact linear time algorithm (PELT) for time series change point detection

PELT algorithm developed by Killick et al. (2012), a method devised for efficiently detecting change points within a time series dataset. Such change points may indicate significant shifts in means or volatility, making this analysis vital for econometric studies and time series forecasting. Time series data often contain points where the underlying statistical properties alter, termed as ‘change points’. Recognizing these points aids in understanding structural breaks, regime changes, or shifts in volatility. The PELT algorithm offers a precise and computationally efficient approach to this detection problem.

Methodology

Dynamic programming

PELT employs a dynamic programming approach to minimize a designated cost function. This function measures how well a given model, inclusive of certain change points, explains the observed data.

Cost function

The cost function evaluates the divergence between the actual data and the data predicted by the model that incorporates the change points. This cost can be predicated upon shifts in means or variances (volatility).

Pruning mechanism

In determining the optimal model, rather than evaluating a vast range of potential models (each denoting different change points), PELT uses a pruning mechanism. By disregarding evidently suboptimal models early on, this mechanism accelerates the overall computation process.

Penalty component

To circumvent overfitting—a scenario where the model aligns exceptionally well with the sample data but performs inadequately on new data—a penalty is imposed for each added change point.

Steps of the PELT Algorithm:

1. Initialization: Begin with the assumption that there's only a single change point at the start of the data.
2. Evaluation Loop: For each data point, t :
 - a. Compute the cost of potential change points up to t .
 - b. Sum up this cost with the penalty for adding an extra change point.
3. Pruning Strategy: At each step, discard change point candidates that have a higher cost than other candidates, ensuring the algorithm remains efficient by focusing only on probable change points.
4. Optimal Change Points Identification: After evaluating all data points, the change points corresponding to the minimal cost function are deemed the optimal change points.
5. Result Consolidation: Collate and present the identified change points in an ordered manner, denoting where significant shifts in the statistical properties of the time series occur.