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Hedging Performance of Green Financial Instruments

José Pedro Alves Dias

Master in Finance

Supervisor:
PhD Paulo Viegas Ferreira de Carvalho, Invited Assistant Professor, ISCTE-IUL

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BUSINESS
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Department of Finance

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Resumo

Esta tese investiga a eficácia de cobertura dos títulos verdes e dos ativos de energia renovável em relação aos instrumentos financeiros tradicionais, em um contexto de elevada volatilidade do mercado acionário durante a crise da COVID-19. Motivado pela crescente relevância das práticas ambientais, sociais e de governança (ESG), o estudo aplica o modelo da Fronteira Eficiente para comparar a estrutura de correlação, a dinâmica de custos e o desempenho dos instrumentos verdes em relação a ativos convencionais, como títulos e commodities, utilizando o Índice de Volatilidade (VIX) como referência para a incerteza do mercado. À medida que o investimento sustentável continua a se expandir, os resultados fornecem insights relevantes sobre o perfil risco–retorno dos ativos verdes e seu papel na diversificação de portfólios, oferecendo subsídios para investidores e formuladores de políticas que buscam atuar em um cenário financeiro cada vez mais orientado pelos princípios ESG.

Palavras-chave: Títulos verdes, Energia renovável, Eficácia de cobertura, Otimização de portfólio, Fronteira Eficiente, Investimentos ESG,

Abstract

This thesis investigates the hedging effectiveness of green bonds and green energy assets against traditional financial instruments amid heightened stock market volatility during the COVID-19 crisis. Motivated by the growing importance of Environmental, Social, and Governance (ESG) considerations, the study applies the Efficient Frontier framework to compare the correlation structure, cost dynamics, and performance of green instruments relative to conventional assets such as bonds and commodities, using the Volatility Index (VIX) as a benchmark for market uncertainty. As sustainable investing continues to expand, the findings provide meaningful insights into the risk-return characteristics of green assets and their role in portfolio diversification, offering guidance to investors and policymakers navigating an increasingly ESG-oriented financial landscape.

Keywords: Green bonds, Green energy, Hedging effectiveness, Portfolio optimization, Efficient Frontier, ESG investing, Volatility Index (VIX), COVID-19 crisis, Financial markets.

Glossary

ASR – Adjusted Sharpe Ratio

BGRN – iShares Global Green Bond ETF

COMF – iShares Commodities Select Strategy ETF

COVID-19 – Coronavirus Disease 2019

DCC-GARCH – Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity

ETF – Exchange-Traded Fund

ESG – Environmental, Social, and Governance

MPT – Modern Portfolio Theory

QCLN – First Trust NASDAQ Clean Edge Green Energy Index Fund

SXR8 – iShares Core S&P 500 UCITS ETF (S&P 500 proxy)

USAG – U.S. Treasury Bond ETF

VIX – CBOE Volatility Index (spot)

VIXY – ProShares VIX Short-Term Futures ETF (tracks short-term VIX futures)

SD – Standard Deviation

SR – Sharpe Ratio

VAR – Variance

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CHAPTER 1

Introduction

The landscape of global finance is undergoing a profound transformation as sustainability becomes an increasingly central theme in investment decisions. Environmental, Social, and Governance (ESG) factors are no longer fringe considerations but are becoming critical components in the strategies of institutional investors, governments, and corporations alike. The growing integration of ESG criteria into investment decision-making is driven by mounting regulatory pressures, increasing public awareness of environmental issues, and the recognition that sustainability is essential for long-term economic resilience and value creation.

Against this backdrop, this thesis embarks on an exploration of the hedging performance and cost associated with green bonds and green energy assets in comparison to traditional financial instruments. Green bonds, which finance projects with positive environmental impacts, have emerged as a prominent tool in the sustainable finance sector. Green energy assets are also gaining traction as viable investment options due to their potential to deliver both environmental and financial returns. This study is motivated by the surge in green energy investments, accentuated by the growing influence of ESG regulations on corporate practices and the broader shift toward a low-carbon economy.

The exponential rise in green energy investments, driven by both regulatory imperatives and heightened environmental consciousness, underscores the need to evaluate the efficacy of these assets in the context of risk management. This thesis aims to contribute to the existing body of knowledge by scrutinizing the hedging potential of green bonds and green energy stocks against traditional instruments such as common bonds, commodities and the Volatility Index (VIX).

This study will employ the Efficient Frontier model, a key concept of Modern Portfolio Theory (MPT), to compare the correlation, cost, and performance of green bonds and green energy assets with traditional financial instruments. The Efficient Frontier model provides a framework to assess how green assets can be integrated into diversified portfolios to enhance returns while managing risk.

The catalyst for this investigation arises from the intersection of two pivotal trends: the ascendancy of green investments and the aftermath of the COVID-19 crisis. As economies grapple with the repercussions of the pandemic, investors are reevaluating the resilience of their portfolios. Against this backdrop, this study seeks to address a critical question: Can green bonds and green energy stocks serve as effective hedges during market volatility?

The remainder of this thesis is organized as follows. Chapter 2 reviews the relevant literature on green finance, volatility indices, and Modern Portfolio Theory, establishing the theoretical foundation for our analysis. Chapter 3 describes the data sources and instruments used in the study. Chapter 4 outlines the methodology, detailing the DCC-GARCH modeling approach and the Efficient Frontier optimization framework applied to evaluate hedging effectiveness. Chapter 5 presents the empirical results, examining how asset correlations evolved during the crisis, comparing portfolio compositions and performance metrics, and discussing the practical implications for investors. Finally, Chapter 6 concludes by synthesizing the key findings, acknowledging limitations, and suggesting future studies.

CHAPTER 2

Literature Review

2.1 Green Finance

The growing emphasis on sustainability and corporate responsibility has led to the development and increased issuance of green financial instruments, such as green bonds. These instruments are designed not only to finance projects with positive environmental impacts but also to enhance a company's overall ESG (Environmental, Social, and Governance) profile. Recent studies highlight the critical role of ESG practices in the issuance of green financial instruments. For example, a study examining the green bond market in China (Wang et al. 2022) found that companies with strong ESG performance are more likely to issue green bonds, and in greater volumes, reflecting investor recognition of sustainable business practices. This suggests that ESG performance is a significant driver in the decision to issue green financial instruments, indicating that investors are increasingly valuing and rewarding corporate commitment to sustainability.

Named for its distinctive features, green bonds are characterized by both their "green" environmental focus and their nature as financial instruments. Consequently, the existing body of literature on green bonds is structured around these two key dimensions.

The green/sustainability literature primarily explores the impact on corporate social responsibility (Zhou et al. 2019) and corporate performance. Within the corporate social responsibility domain, the literature reveals that the announcement of green bond issuance positively affects companies' stock prices. Additionally, green bonds contribute to improved profitability, operational performance, and innovation capacity, showcasing tangible economic and environmental benefits. As maturing green bonds increase, their role in enhancing companies' CSR (Corporate Social Responsibility) activities gains significance, aligning with the growing popularity of investment approaches emphasizing environmental, social, and corporate governance considerations. In regards to corporate performance, Alonso-Conde

et al. concluded that green bonds provide a higher return to shareholders when compared to conventional financing.

On the other hand, the bond/finance literature emphasizes the green bond risk premium. According to Bachelet et al. (2019), green bonds may have a negative risk premium, allowing green investments to be financed at a reduced cost. This could be attributed to investors' willingness to pay for environmental sustainability or the lower exposure to stakeholder risks associated with green investments. However, this is contingent on issuer reputation or the presence of green verification to mitigate information asymmetry and prevent greenwashing. Additionally, the author demonstrated that green bonds exhibit higher yields, lower variance, and increased liquidity when compared to common bonds. Also, it has been observed that green bonds display an asymmetric volatility characteristic, being more responsive to positive shocks than negative ones (Park et al. 2020). This study also identifies volatility spillover effects between the green bonds and equity markets. Remarkably, while volatility spills over, neither market significantly responds to negative shocks from the other, which is a good indicator of the hedging performance of this instruments against market crashes.

Further insights into green bonds reveal their role as a bridge between sustainable finance and traditional markets. According to Guo et al. (2021) empirical evidence suggests that green bonds share many characteristics with traditional high-quality bonds (e.g., Treasury and investment-grade corporate bonds), green bonds show limited interaction with general equities, renewable energy stocks, and crude oil markets, highlighting their distinct risk-return profile. This distinctiveness makes them an attractive diversification tool for portfolios composed of equities or oil-related assets, particularly over longer time horizons. Moreover, despite their shared environmental focus, green bonds and renewable energy stocks behave as separate asset classes, appealing to different investor types.

2.2 VIX

Introduced by the Chicago Board Exchange (CBOE) in 1993, the CBOE Volatility Index (VIX) initially gauged the 30-day expected volatility. This measurement was based on eight near-the-money S&P 100 options from the two closest maturities, essentially constituting an average of Black-Scholes implied volatilities.

In a notable development in late 2003, the CBOE revised the VIX computation method, adopting a model-free approach inspired by the theoretical contributions

of Britten-Jones et al. (2000), Carr et al. (1998), and Demeterfi et al. (1999). The updated VIX continued to assess the 30-day implied volatility but shifted to using S&P 500 index (SPX) options. These options encompassed all available strikes from maturities falling between 23 and 37 days specifically, the near-term and next-term maturities. As the near-term option approached maturity within 23 days, the next-term option transitioned to near-term, and a new option assumed the next-term position.

The revamped VIX not only maintained its focus on the 30-day implied volatility but also achieved a more comprehensible economic significance compared to its predecessor. Carr et al. (2005) noted that this change was motivated in part by the desire for the VIX to represent the price of a linear portfolio of options.

The VIX's investment benefits have drawn notice right away. Stanton explains that the S&P 500 index and the VIX have a negatively correlated relationship. All this characteristics make the VIX index the perfect benchmark for our analysis.

2.3 Modern Portfolio Theory

Markowitz's seminal work (Markowitz 1952) laid the foundation for Modern Portfolio Theory. His paper remains a cornerstone of investment strategy and portfolio management. MPT introduces the concept of diversification to minimize risk and maximize returns.

According to Markowitz's theory, investors can construct an optimal portfolio by carefully selecting a combination of assets that achieve the highest return for a given level of risk.

A key insight from Markowitz's research is that portfolio risk is influenced not only by the individual risks of the assets but also by the correlations between their returns. In particular, combining assets with low or negative correlations can reduce the portfolio's overall volatility by counterbalancing the effects of assets moving in opposite directions.

2.3.1 Performance Metrics

Sharpe Ratio: Developed by Sharpe (1994), the Sharpe Ratio measures the risk-adjusted performance of an investment by assessing the excess return per unit of risk (standard deviation).

$$\text{Sharpe Ratio} = \frac{R_p - R_f}{\sigma_p} \tag{2.1}$$

Where:

R_p is the expected portfolio return,

R_f is the risk-free rate of return,

σ_p is the standard deviation of the portfolio's returns.

A portfolio's higher Sharpe Ratio demonstrates its superior effectiveness in delivering returns relative to its risk level. This enhanced performance stems from combining diverse assets that respond differently to varying market conditions.

To take into account higher moments of return distribution Pézier (2004) proposed an Adjusted Sharpe Ratio:

$$ASR = SR\left(1 + \left(\frac{S \times SR}{6}\right) - \left(\frac{(K-3) \times SR^2}{24}\right)\right) \tag{2.2}$$

Where:

S is the skewness of the return distribution,

K is the kurtosis of the return distribution,

SR is the Sharpe Ratio.

By computing the Adjusted Sharpe Ratio for the different portfolios that will be used in this study, we can determine whether green financial instruments offer a superior risk-adjusted performance compared to more traditional instruments.

CHAPTER 3

Data

To conduct a comprehensive analysis of the hedging performance of various financial instruments, we need to get data for all of them.This data, extracted from Bloomberg, encompasses daily closing prices for the following key instruments:

- **Stock Market:iShares Core S&P 500 UCITS ETF (SXR8)** - The simulation of the stock market will be executed using the largest ETF by size that follows the S&P 500 Index.
- **Commodities: L&G Longer Dated All Commodities UCITS ETF (COMF)** - This ETF tracks the Bloomberg Commodity Total Return Index giving us exposure to all types of commodities (gold, crude oil, live stock etc) according to their liquidity.
- **Bonds: SPDR Bloomberg US Aggregate Bond UCITS ETF (USAG)** - This ETF seeks to track the Bloomberg US Aggregate Bond index and will simulate a diversified exposure to the US Corporate and Governmental bond market.
- **Green Stocks: First Trust Nasdaq Clean Edge Green Energy UCITS ETF (QCLN)** - This index tracks the performance of companies that are manufacturers, developers, distributors, and/or installers of clean-energy technologies.
- **Green Bonds: iShares USD Green Bond ETF (BGRN)** - This ETF seeks to track the investment results of an index composed of U.S. dollar-denominated investment-grade green bonds that are issued by U.S. and non-U.S. issuers to fund environmental projects.
- **Volatility Index: ProShares VIX Short-Term Futures ETF (VIXY)** - This VIX ETF will be used as a benchmark for our study.

For the risk free interest rate, the 3-month Treasury Bill rate swill serve as a proxy. The dataframe considered for this study ranges from January 1, 2020 to January 1, 2021, which corresponds to the COVID-19 crisis.

CHAPTER 4

Methodology

The core objective of this study is to evaluate whether green bonds and renewable energy assets can serve as effective hedging instruments against equity market volatility during the COVID-19 crisis. Specifically, we compare their performance to traditional hedging instruments—commodities and conventional bonds—when paired with S&P 500 exposure. To accomplish this, we apply the Efficient Frontier framework, which allows us to systematically evaluate risk-return trade-offs across different portfolio combinations.

Our approach centers on measuring how correlations, volatilities, and portfolio compositions shifted between two distinct market regimes: a stable pre-COVID period (2019) and the turbulent COVID period (2020). By isolating these two windows, we can identify whether green instruments exhibit structural differences in their hedging properties under stress conditions

4.1 Data Processing

We begin by collecting daily adjusted closing prices for all assets from Bloomberg. Adjusted prices account for corporate actions such as dividends, stock splits, and share offerings, ensuring that return calculations reflect true economic performance rather than mechanical price adjustments.

From these prices, we compute logarithmic returns:

$$\textit{Log return} = \ln\left(\frac{P_t}{P_{t-1}}\right) \tag{4.1}$$

where P_t is the price of the asset at time t, and P_{t-1} is the price of the asset at the previous period $t-1$: the previous day. Logarithmic returns are preferred in financial econometrics because they are time-additive, symmetric around zero, and better suited for continuous-time modeling than simple arithmetic returns.

For the risk-free rate, we use the 3-month U.S. Treasury Bill rate as a proxy. This choice reflects the conventional view that short-term government securities

carry negligible credit risk. Since our analysis operates on a daily frequency, we convert the annualized Treasury rate to a daily equivalent by dividing by 252: the standard number of trading days in a year.

4.2 Modelling Time-Varying Covariances and Correlations

Financial markets do not exhibit constant correlations or volatilities over time. During periods of crisis, asset relationships can shift dramatically—correlations may spike, diversification benefits may erode, and previously uncorrelated assets may suddenly move in tandem. To capture these dynamics, we employ the Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH) model developed by Engle (2002).

The DCC-GARCH framework has two key components:

- **GARCH component:** Models the time-varying volatility of each individual asset's return series, capturing the well-known phenomenon of volatility clustering in financial markets.
- **DCC component:** Estimates a time-varying conditional correlation matrix, which evolves over time and reflects how asset relationships change in response to market conditions.

This modeling strategy is particularly well-suited to our research question. Unlike static correlation estimates, which assume relationships remain constant, the DCC-GARCH approach explicitly recognizes that correlations can shift rapidly during stress episodes—precisely the scenario we examine during COVID-19.

We estimate the DCC-GARCH parameters using a rolling window of 30 trading days (approximately one calendar month). This window size is not arbitrary. The VIX, our benchmark volatility measure, represents the market's expectation of S&P 500 volatility over the next 30 calendar days. By aligning our empirical estimation window with this convention, we ensure direct comparability between realized and implied measures of risk. Moreover, a one-month horizon is standard in risk management practice for portfolio rebalancing, Value-at-Risk calculations, and volatility targeting exercises.

We roll the estimation window forward one day at a time, generating a sequence of covariance and correlation estimates throughout each period. The final covariance and correlation matrices—those corresponding to the end of each period—serve as inputs to the portfolio optimization. This approach ensures that our

portfolio weights reflect the most recent market conditions rather than outdated relationships.

The model is implemented in Python using the arch library, which provides robust, well-tested routines for GARCH estimation and is widely used in both academic research and industry practice.

4.3 Portfolio Optimisation

With time-varying covariance matrices in hand, we turn to portfolio construction. Our optimization problem seeks to maximize the Adjusted Sharpe Ratio subject to a fixed 50% allocation to the S&P 500 ETF (SXR8). This constraint ensures that all portfolios maintain identical equity exposure, allowing us to isolate the marginal contribution of each hedging instrument.

The standard Sharpe Ratio measures excess return per unit of volatility. However, the Sharpe Ratio assumes that returns are normally distributed, which is rarely the case in practice. Financial returns typically exhibit negative skewness (larger losses than gains) and excess kurtosis (fat tails). To account for these higher moments, we use the Adjusted Sharpe Ratio proposed by Pézier 2004.

The portfolio returns are calculated as the weighted average of the individual asset returns:

$$R_p = \sum_{i=1}^{n} \omega_i \times R_i \tag{4.2}$$

where ω_i represents the weight of asset i in the portfolio, and R_i is the expected return.

With regards to the portfolio variance, it is calculated as the weighted sum of covariances:

$$\sigma_p^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_i \times \omega_j \times \sigma_{ij} \tag{4.3}$$

where σ_{ij} represents the covariance between asset i and asset j.

We construct and compare three portfolio strategies:

- **Traditional Portfolio:** 50% SXR8 + hedging instruments from USAG, COMF
- **Green Portfolio:** 50% SXR8 + hedging instruments from QCLN, BGRN
- **Benchmark Portfolio:** 50% SXR8 + 50% VIX (ETF tracking short-term VIX futures)

The optimization is performed separately for the 2019 and 2020 periods. Skewness and kurtosis are calculated using Excel's built-in SKEW and KURT functions, and the constrained optimization is solved using Excel Solver. The constraints are: no short sales, and weights sum to one.

By comparing Adjusted Sharpe Ratios across periods and strategies, we can evaluate how the hedging effectiveness of green instruments evolved from the stable pre-pandemic environment to the volatile COVID regime

Naming convention. Throughout the thesis, the ProShares VIX Short-Term Futures ETF (VIXY) is referred to simply as "VIX" for brevity. Strictly speaking, VIXY tracks a short-term VIX futures index rather than the VIX spot index.

CHAPTER 5

Empirical Results and Analysis

This chapter presents the empirical findings from our Efficient Frontier optimization and time-varying correlation analysis. We examine how the behavior of traditional and green financial instruments changed between two distinct market environments: the calm pre-COVID period (January–December 2019) and the turbulent COVID period (January–December 2020). The results reveal not only how asset relationships shifted under stress, but also what these shifts mean for practical portfolio construction and risk management.

5.1 Understanding How Asset Relationships Changed: Pre-COVID vs COVID

To understand how well different assets hedge equity risk, we need to examine their correlations and covariances with the stock market. Figure 1 shows the correlation structures.

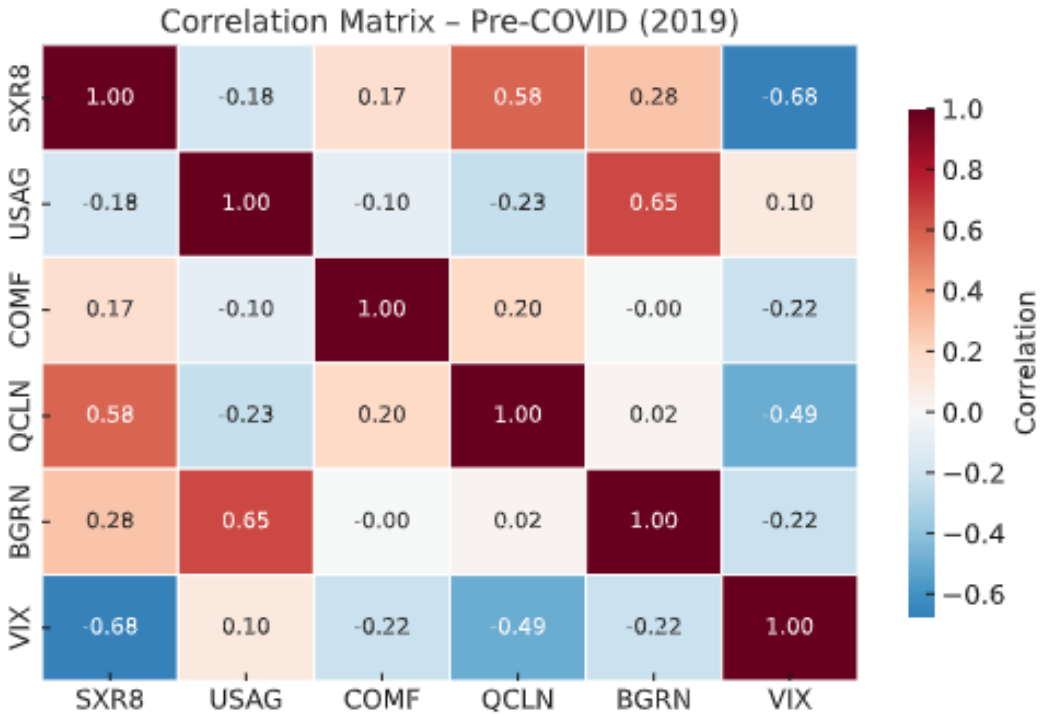
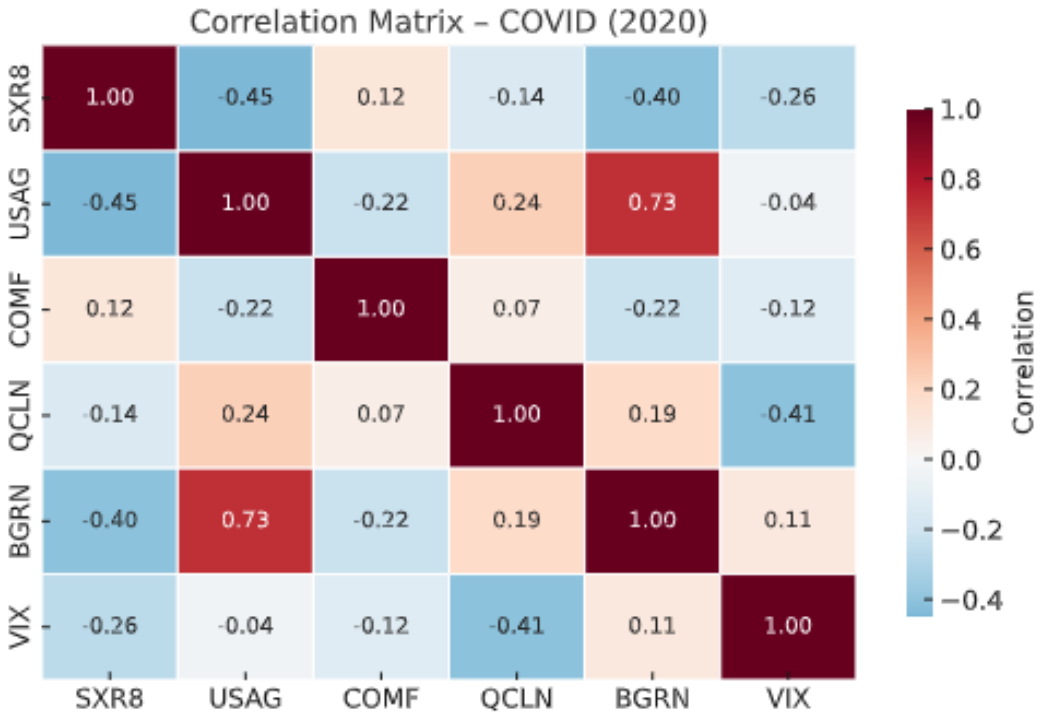


FIGURE 1. Correlation matrices during the Pre-COVID and COVID periods.



(continued)

Figure 1 contrasts the correlation structures across the two regimes and clarifies the hedging implications. Dar red colors represent a higher positive correlation, while blue colors represent a strong negative correlation.

Before the pandemic, the financial world behaved in relatively predictable ways. Traditional bonds (USAG) showed a modest negative correlation with stocks (SXR8: -0.18), providing the diversification benefit we expect from fixed-income securities. The VIX exhibited a strong negative correlation with equities (-0.68), confirming its role as a "fear gauge" that typically rises when stocks fall. Green bonds (BGRN) showed a weak positive correlation with stocks (+0.28), suggesting they moved somewhat independently of equity markets. Meanwhile, green energy stocks (QCLN) behaved much like conventional equities, displaying a strong positive correlation with the S&P 500 (+0.58). This makes intuitive sense: despite their environmental focus, renewable energy companies are still equities subject to similar market forces as other stocks.

During 2020, nearly every correlation shifted, some dramatically. The most striking transformations occurred in green instruments:

- Green bonds (BGRN) flipped from weakly pro-cyclical (+0.28) to moderately defensive (-0.40). Suddenly, green bonds began acting as a meaningful hedge against equity declines, moving opposite to stock prices during market stress.
- Green energy stocks (QCLN) also reversed direction, shifting from strongly pro-cyclical (+0.58) to slightly counter-cyclical (-0.14). While they didn't become as defensive as bonds, they clearly decoupled from the broader equity market's movements.

Traditional hedges also strengthened. Conventional bonds (USAG) became more negatively correlated with stocks (-0.18 → -0.45), reinforcing their defensive characteristics during the crisis.

This behavior aligns with the classic ”flight to quality” phenomenon, where investors flee risky assets and pile into government securities during periods of extreme uncertainty.

One unexpected finding deserves closer analysis: the correlation between stocks and the VIX actually weakened during the pandemic (-0.68 → -0.26).

The answer lies in understanding how volatility behaves under extreme stress. When the pandemic struck in March 2020, the VIX spiked violently. But volatility could not sustain those levels indefinitely. As markets adapted to the “new normal” of pandemic conditions, the VIX gradually declined even while uncertainty remained elevated and equity prices continued to be volatile.

This created a temporal mismatch: stocks experienced sustained turbulence through 2020, but the VIX no longer responded proportionally to each swing. The initial shock was so extreme that subsequent fluctuations—though still large by historical standards—appeared muted by comparison. This phenomenon, documented by Just et al. 2020, can be viewed as a structural break in the equity–volatility relationship under crisis conditions.

The implication is crucial for risk managers: volatility-based hedges (e.g. VIX futures) may deliver their strongest protection during the initial phase of a crisis, but lose effectiveness as elevated volatility becomes the status quo. This helps explain why the covariance between SXR8 and VIX actually became less negative (in absolute terms) during COVID, despite the period’s extreme turbulence.

5.2 How Individual Assets Performed: Prices and Return

Figure 2 provides a visual narrative of the crisis, showing both price trajectories and return distributions for each asset.

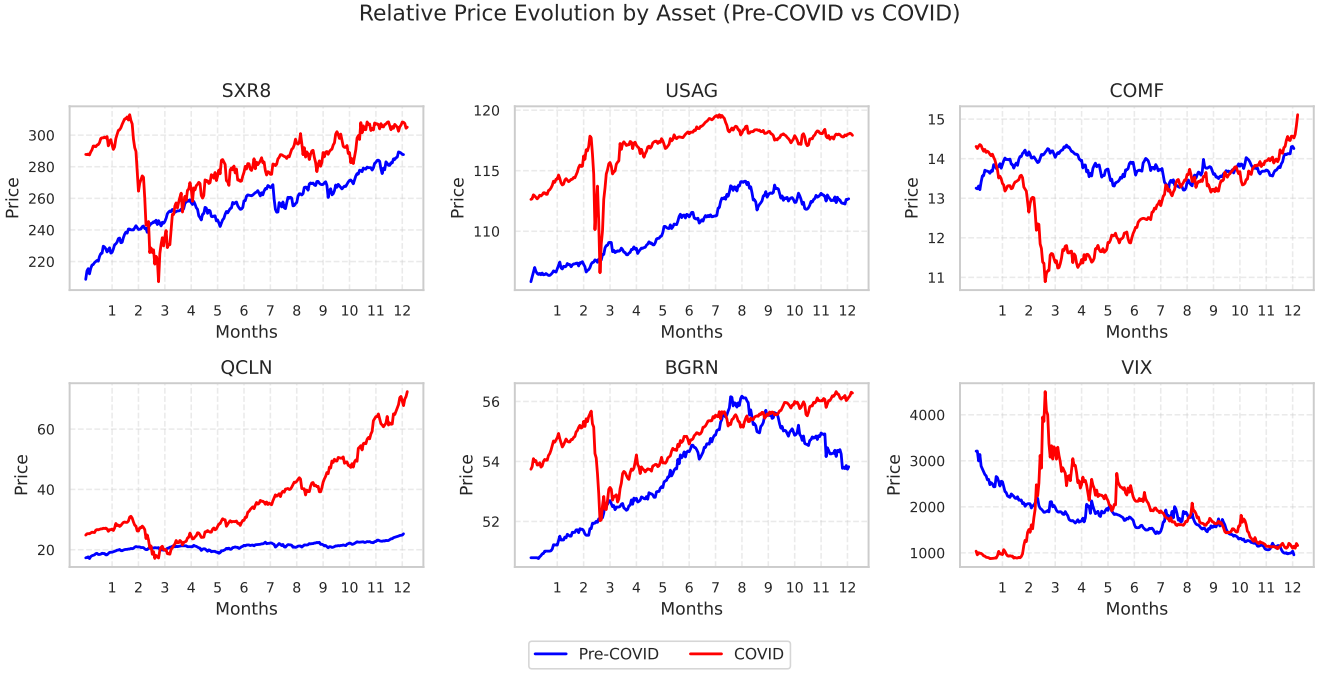
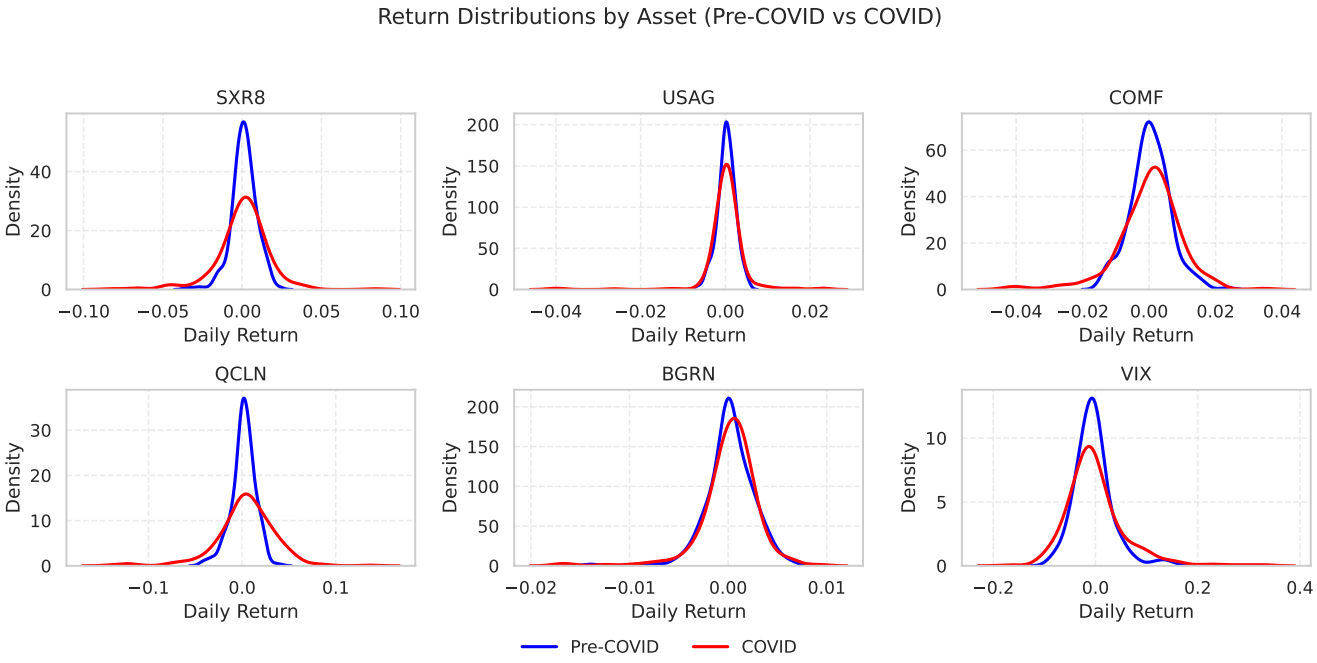


FIGURE 2. Prices and returns distributions of individual assets during Pre-COVID and COVID periods.



(continued)

The pre-COVID price charts tell a story of complacency. Nearly every asset drifted upward in a steady, orderly fashion throughout 2019, a continuation of the decade-long bull market that followed the 2008 financial crisis. SXR8 and QCLN climbed in tandem, while BGRN maintained its characteristically stable, low-volatility trajectory.

March 2020 interrupted this tranquility. The sudden onset of COVID-19 triggered simultaneous crashes across nearly all asset classes—a stark reminder that during systemic crises, diversification benefits can evaporate as correlations spike toward one. Yet the recovery patterns that followed were strikingly heterogeneous, revealing important differences in how various assets respond to stress:

- **Green energy (QCLN)** experienced the most dramatic V-shaped recovery. After initially plummeting alongside other equities, QCLN rebounded with remarkable strength, ultimately ending 2020 well above pre-crisis levels. This performance likely reflects the intersection of several factors: pandemic-driven interest in clean technology, accommodative monetary policy favoring growth stocks, and accelerating policy support for renewable energy.
- **Bonds (USAG and BGRN)** demonstrated resilience, declining modestly during the initial shock but recovering more quickly than equities. USAG stabilized slightly earlier than BGRN, consistent with Treasuries' status as the ultimate safe haven, but both showed the defensive characteristics expected of fixed-income instruments.
- **Commodities (COMF)** struggled throughout 2020, exhibiting a slow, grinding recovery. This sluggish performance reflects the demand destruction caused by lockdowns, with economic activity curtailed worldwide, demand for industrial commodities, energy, and raw materials collapsed..

- **VIX** tells a differnt story: a massive spike in March 2020 reflecting panic-level uncertainty, followed by a gradual but incomplete normalization. The fact that VIX remained elevated throughout the year never fully returning to 2019 levels—confirms that uncertainty persisted even as markets stabilized.

The bottom panels of Figure 2 reveal something the price charts cannot: the fundamental change in the shape of risk. Compare the return distributions before and during COVID. In 2019, most assets displayed relatively tight, bell-shaped distributions centered near zero, exactly what we expect during calm markets.

In 2020, these distributions underwent some changes. They widened considerably (higher volatility), developed fatter tails (more extreme events), and became more asymmetric. Table 1 quantifies these changes through skewness and kurtosis measures.

TABLE 1. Descriptive Statistics of Individual Asset Returns Before and During COVID-19

Asset	**Period**	**Mean**	**Skewness**	**Kurtosis**
SXR8	Pre-COVID	0.00118	−0.61	2.28
	COVID	0.00026	−0.78	5.61
USAG	Pre-COVID	0.00023	−0.32	0.49
	COVID	0.00019	−3.07	29.59
COMF	Pre-COVID	0.00031	0.20	0.88
	COVID	0.00008	−0.99	3.85
QCLN	Pre-COVID	0.00141	−0.56	1.20
	COVID	0.00408	−0.81	4.41
BGRN	Pre-COVID	0.00022	−1.01	5.22
	COVID	0.00018	−1.97	9.74
VIX	Pre-COVID	−0.00450	1.12	3.19
	COVID	0.00023	1.77	6.33

Across nearly all assets, kurtosis values increased sharply during COVID-19, confirming the emergence of fatter tails and a higher probability of extreme daily returns. USAG's kurtosis exploded from 0.49 to 29.59, meaning the bond market experienced wildly more frequent extreme daily moves than normal distribution theory would predict. Even BGRN, despite its defensive nature, saw kurtosis nearly double (5.22 → 9.74).During the March crisis, Treasury markets, normally the most liquid and stable in the world, briefly seized up as dealers withdrew from market-making and investors frantically repositioned. This created occasional dramatic price swings even in supposedly "safe" assets.

In terms of skewness, most assets became more negatively skewed during the pandemic, meaning that downside movements became both larger and more frequent. SXR8 and QCLN show

moderate left-skewness (-0.78 and -0.81, respectively), aligning with the visibly wider and flatter shapes of their COVID return distributions in Figure 2.

COMF also shifted from slightly positive skewness to negative values (0.20 to -0.99), illustrating its asymmetric losses during the March 2020 collapse. Meanwhile, USAG's strong negative skewness (-3.07) reflects occasional large downward yield adjustments associated with panic-driven rebalancing.

Conversely, the VIX maintained positive skewness throughout, which became even more pronounced during COVID (1.12 to 1.77), mirroring its tendency to experience large positive jumps during volatility spikes. The elevated kurtosis of the VIX (3.19 to 6.33) further confirms that volatility shocks became more frequent and severe, consistent with the extreme right-tail behavior in its return distribution.

Overall, both the graphical and statistical evidence demonstrate that the COVID crisis was marked by a general expansion in distributional width (higher volatility), heavier tails (increased kurtosis), and more pronounced asymmetry in risk assets (negative skewness), while USAG and BGRN preserved their defensive characteristics albeit with occasional tail shocks.

5.3 Capital Allocation: Understanding Portfolio Weights

The asset weights for both the traditional (Portfolio 1) and green (Portfolio 2) portfolios are presented in Table 2. The optimization imposed a 50% allocation to SXR8 in both portfolios, ensuring comparability in hedging performance.

Table 2. Portfolio weights before and during COVID-19

Portfolio	**Period**	**SXR8**	**Hedge Asset 1**	**Hedge Asset 2**
Traditional (USAG, COMF)	Pre-COVID	0.50	0.50 (USAG)	0.00 (COMF)
Traditional (USAG, COMF)	COVID	0.50	0.50 (USAG)	0.00 (COMF)
Green (QCLN, BGRN)	Pre-COVID	0.50	0.23 (QCLN)	0.27 (BGRN)
Green (QCLN, BGRN)	COVID	0.50	0.40 (QCLN)	0.10 (BGRN)

The traditional portfolio maintained an unchanged allocation throughout both periods: 50% stocks (SXR8) and 50% bonds (USAG), with zero weight assigned to commodities (COMF). This stability reflects the hedging effectiveness of a simple stock-bond allocation even under extreme stress.

Commodities recive no allocation because during COVID, COMF's variance increased (0.00004 $\rightarrow$ 0.00005) while its expected return declined (0.00031 $\rightarrow$ 0.00008). In mean-variance terms, commodities offered inferior compensation for their volatility compared to bonds. USAG, despite its own increased volatility, maintained a more favorable profile: low variance (0.00005 $\rightarrow$ 0.00003), reasonable downside protection (correlation with SXR8 of -0.45), and stable expected return (0.00023 $\rightarrow$ 0.00019).

The green portfolio, by contrast, underwent significant rebalancing between periods. In 2019, the optimizer split the 50% hedging allocation relatively evenly between QCLN (23%) and BGRN (27%). This balance reflected QCLN's higher expected return (0.00141) offset by BGRN's superior diversification properties (lower correlation with SXR8).

During COVID, the allocation shifted dramatically toward green equities: QCLN rose to 40% while BGRN fell to just 10%.

The justification can be given by the intersection of three factors:

- **Return enhancement:** QCLN's mean daily return surged during COVID (0.00141 → 0.00408), making it the highest-returning asset in our universe aside from the benchmark. The strong performance of the renewable energy sector reflected both favorable public policies and a pandemic-accelerated shift toward sustainable technologies.
- **Correlation reversal:** QCLN's correlation with SXR8 flipped from positive to negative (+0.58 → -0.14), meaning green energy stocks began providing diversification benefits they hadn't offered before. This structural shift altered QCLN's role in the portfolio, from a growth-oriented equity exposure to a partial hedge.
- **Risk-return optimization:** Although QCLN's variance increased substantially (0.00012 → 0.00077), the optimizer determined that its improved returns and altered correlation structure more than compensated for the additional volatility. Put simply, the expected-return per unit of risk improved enough to justify higher exposure.

BGRN's allocation declined not because it performed poorly, it continued to offer stable, defensive characteristics, but because its modest returns (0.00022 → 0.00018) and low volatility meant it contributed less to the portfolio's expected return. The optimizer effectively made a calculated trade: accept somewhat more volatility from QCLN in exchange for meaningfully higher expected returns, while still maintaining some BGRN exposure for stability.

This rebalancing illustrates an important principle: optimal portfolio construction isn't about choosing safe assets versus risky assets, it's about finding the combination that best balances expected return against total portfolio volatility, accounting for how assets move together. The fact that QCLN's allocation increased during a crisis demonstrates that correlation structure can matter more than individual asset volatility in determining hedging effectiveness.

Overall, these results demonstrate how the optimizer adapted to shifting market dynamics by prioritizing assets with improved return prospects (such as QCLN) while maintaining exposure to defensive components (USAG and BGRN) that offered protection against systemic shocks. The combination of changes in expected returns, volatility, and correlations ultimately dictated the portfolio's rebalancing, reflecting a trade-off between return enhancement and risk containment.

5.4 Performance Comparison

Having examined correlations, return distributions, and portfolio weights separately, we now integrate these elements to evaluate overall performance. Table 4 summarizes the key statistics.

TABLE 3. Portfolio performance statistics before and during COVID-19

Portfolio	**Period**	**Exp. Return**	**Std. Dev.**	**Skew.**	**Kurt.**
Traditional (USAG, COMF)	Pre-COVID	0.00071	0.0038	-0.55	2.43
Traditional (USAG, COMF)	COVID	0.00022	0.0036	-1.33	10.84
Green (QCLN, BGRN)	Pre-COVID	0.00097	0.0059	-0.51	1.09
Green (QCLN, BGRN)	COVID	0.00182	0.0113	-0.83	4.54
Benchmark (SXR8/VIX)	Pre-COVID	-0.00170	0.0109	1.18	3.53
Benchmark (SXR8/VIX)	COVID	0.00310	0.0226	1.29	7.03

The green portfolio achieved the highest expected return during COVID (0.00182 daily), substantially outperforming the traditional portfolio (0.00022). This difference in returns reflects the extraordinary performance of renewable energy equities during 2020.

However, this return advantage came at a cost: the green portfolio's standard deviation more than doubled from 2019 to 2020 ($0.0059 \rightarrow 0.0113$), reflecting the increased volatility of its equity-heavy allocation. The traditional portfolio, by contrast, maintained nearly constant volatility across both periods ($0.0038 \rightarrow 0.0036$), demonstrating the stabilizing power of a large Treasury allocation.

The benchmark (50% SXR8 / 50% VIX) posted the highest expected return during COVID (0.00310) but also exhibited nearly double the volatility (0.0226) of the green portfolio. This extreme volatility stems from the VIX component's massive swings during the crisis period, confirming that while volatility-based hedges can be profitable, they are extraordinarily unstable.

Both active portfolios experienced increases in kurtosis, but the magnitudes differed. The traditional portfolio's kurtosis surged from 2.43 to 10.84, a near-quintupling that reflects the extreme tail events in Treasury markets during March 2020. The green portfolio's kurtosis also rose ($1.09 \rightarrow 4.54$) but remained substantially lower, suggesting somewhat less severe tail risk despite its higher equity allocation.

Skewness tells a complementary story. Both portfolios exhibited negative skewness during COVID, but again the traditional portfolio showed the more extreme value (-1.33 vs. -0.83). The explanation lies in the nature of the tail events: when Treasuries experienced liquidity stress in March 2020, the resulting price movements were sharp and concentrated, creating pronounced negative skewness. The green portfolio's losses, while substantial, were more distributed across multiple smaller events, resulting in less severe skewness.

The analysis of Sharpe and adjusted Sharpe ratios in Table 4 complements the examination of expected returns presented earlier by accounting for the volatility inherent in each portfolio's performance. While expected returns provide a direct measure of profitability, the Adjusted Sharpe ratio contextualizes these returns relative to the total risk taken by the investor. This distinction is crucial, as the return distributions in Figure 2 demonstrated substantial differences in volatility and tail behavior between the pre-COVID and COVID periods.

TABLE 4. Sharpe and Adjusted Sharpe Ratios for each portfolio

Portfolio	**Period**	**Sharpe Ratio**	**Adjusted Sharpe Ratio**
Traditional (USAG, COMF)	Pre-COVID	0.1658	0.1628
Traditional (USAG, COMF)	COVID	0.0386	0.0382
Green (QCLN, BGRN)	Pre-COVID	0.1521	0.1499
Green (QCLN, BGRN)	COVID	0.1541	0.1502
Benchmark (SXR8/VIX)	Pre-COVID	-0.1595	-0.1539
Benchmark (SXR8/VIX)	COVID	0.01	0.01

Table 4 reports the Sharpe and adjusted Sharpe ratios for each portfolio across the two periods. The results highlight how the transition from a stable pre-COVID environment to the turbulent conditions of 2020 significantly altered the efficiency of both traditional and green allocations.

During 2019, both strategies performed similarly on a risk-adjusted basis. The traditional portfolio edged ahead slightly (Adjusted Sharpe: 0.1628 vs. 0.1499), but the difference was modest. This parity reflects the favorable conditions of 2019, when most assets delivered positive returns with relatively low volatility. In such environments, the choice between traditional and green strategies matters less.

The benchmark's negative Adjusted Sharpe (-0.1539) during this period reflects the cost of holding VIX exposure in a calm market. When volatility is declining or stable, VIX-based hedges lose money, dragging down portfolio returns without providing any benefits.

The crisis revealed stark differences in portfolio resilience. The traditional portfolio's Adjusted Sharpe Ratio collapsed by 76% (0.1628 $\rightarrow$ 0.0382), reflecting both diminished returns and the deterioration in tail risk characteristics (extreme kurtosis and skewness). While the portfolio remained profitable and defensive, its efficiency decreased substantially.

The green portfolio, remarkably, maintained almost identical risk-adjusted performance across both periods (0.1499 $\rightarrow$ 0.1502), effectively flat despite the market volatility. This stability is the study's most significant finding. While the green portfolio experienced higher absolute volatility during COVID, its superior return generation and managed tail risk meant that the overall risk-return trade-off remained roughly constant.

Meanwhile, he benchmark portfolio's Adjusted Sharpe improved from negative (-0.1539) to slightly positive (0.01) during COVID, confirming that VIX-based hedges delivered some protection during the crisis. However, even during COVID, the benchmark underperformed both active strategies, highlighting the high cost of maintaining direct volatility exposure.

5.5 Pratical Implications

The empirical results carry several important implications for portfolio construction and risk management, particularly in periods of heightened market uncertainty such as the COVID-19 crisis.

The green portfolio's resilience during COVID reflected structural differences in how green assets respond to systemic shocks. Specifically:

- **Green bonds (BGRN)** demonstrated defensive characteristics that strengthened during stress, flipping from weak positive to meaningful negative correlation with equities. This behavior suggests that green bonds may offer diversification benefits distinct from conventional bonds, possibly due to their unique investor base or structural features.
- **Green energy equities (QCLN)** decoupled from broader equity markets during the crisis, shifting from pro-cyclical to counter-cyclical. This decoupling likely reflects sector-specific dynamics, renewable energy benefited from policy support and secular trends that partially insulated it from pandemic-driven economic damage.

For portfolio managers, this suggests that ESG-oriented assets shouldn't be viewed merely as ethical sound investments. They can serve functional roles in risk management and diversification, particularly during periods when traditional asset class relationships break down.

The weakening correlation between the VIX and equities during COVID highlights a critical limitation of volatility-based hedges: they work best during initial shock phases but lose effectiveness when elevated volatility becomes the new normal. This has practical implications:

- VIX-based hedges (options, futures, ETFs) should be viewed as tactical protection against acute shocks, not strategic long-term holdings
- Portfolio protection strategies should combine multiple hedge types: volatility instruments, defensive sectors, and alternative assets, rather than relying exclusively on volatility-based products
- When volatility is already elevated, traditional defensive assets (bonds, low-correlation equities) offer more reliable ongoing protection than additional volatility exposure

The benchmark portfolio posted the highest absolute returns during COVID but delivered the lowest risk-adjusted performance, with an Adjusted Sharpe barely positive (0.01). The green portfolio illustrates this principle in reverse: despite posting lower absolute returns than the benchmark, it achieved far superior risk-adjusted performance by managing volatility and tail risk more effectively. For most investors, particularly institutions with liability constraints or even possibly individuals approaching retirement, the green strategy's stable efficiency would be preferable to the benchmark's.

One common criticism of ESG investing is that it prioritizes ethical considerations over financial prudence, potentially sacrificing returns or accepting unnecessary risks. This results challenge this narrative with the green portfolio maintaining a robust risk-adjusted performance.

The key insight is that ESG integration should be risk-aware while not sacrificing the returns. Green assets exhibited higher volatility during COVID, but the optimizer recognized this and adjusted allocations accordingly, maintaining some BGRN exposure for stability while overweighting QCLN to capture its improved return profile.

The result was a portfolio that aligned with sustainability objectives while delivering competitive risk-adjusted returns.

CHAPTER 6

Conclusion

This thesis examined the hedging effectiveness and portfolio performance of green financial instruments, specifically green bonds and renewable energy assets, relative to traditional hedging tools during the COVID-19 crisis. By applying the Efficient Frontier framework and Dynamic Conditional Correlation GARCH modeling, we evaluated how correlation structures, volatility dynamics, and risk-adjusted returns evolved between the stable pre-pandemic period of 2019 and the volatile conditions of 2020.

The empirical findings reveal several insights. First, green instruments underwent substantial structural transformations during the crisis. Green bonds shifted from weakly pro-cyclical to moderately defensive, demonstrating enhanced diversification benefits precisely when traditional correlations began to decrease. Renewable energy equities separated from broader equity markets, transitioning from strongly positive to slightly negative correlation with the S&P 500. These shifts reflected fundamental changes in how green assets respond to systemic shocks, driven by sector-specific policy support.

Second, the green portfolio maintained remarkably stable risk-adjusted performance across both periods, with its Adjusted Sharpe Ratio remaining essentially flat despite dramatically different market conditions. This stability contrasts sharply with the traditional portfolio, whose risk-adjusted performance deteriorated by 76% during COVID-19. While the green portfolio experienced higher absolute volatility during the crisis, its superior return and more favorable tail risk characteristics meant that the overall efficiency remained stable. This resilience suggests that green assets offer structural diversification properties that extend beyond conventional asset classes.

Third, this analysis highlights important limitations of volatility-based hedging strategies. The weakening correlation between equities and the VIX during COVID-19 demonstrates that direct volatility exposure provides strongest protection during major shock phases but loses effectiveness when elevated uncertainty becomes persistent. The benchmark portfolio, despite having the highest absolute returns, delivered inferior risk-adjusted performance compared to both active strategies, highlighting the critical distinction between nominal gains and efficiency.

From a practical standpoint, these results carry meaningful implications for portfolio construction in an increasingly ESG-oriented investment landscape. Green financial instruments should not be viewed exclusively from an ethical perspective but recognized as functional components of diversified portfolios offering distinct risk-return characteristics. The maintained efficiency of the green portfolio during stress defies the perception that ESG integration necessarily compromises

financial performance. Rather, our findings suggest that the incorporation of green assets can enhance portfolio resilience without sacrificing risk-adjusted returns.

This study contributes to the growing literature on sustainable finance by providing empirical evidence of green assets' hedging effectiveness during a major crisis period. However, several limitations need to be recognized. The analysis focuses on a single crisis episode, and the generalizability of these findings to other stress scenarios remains an open question. Additionally, the relatively short time horizon and reliance on ETF proxies may not fully capture the nuances of direct green bond or renewable equity holdings.

Future research could extend this framework by examining longer time periods including multiple crisis episodes, incorporating a broader universe of green instruments, and exploring whether the structural changes observed during COVID-19 persisted in subsequent years. Investigation of geographical variations in green asset behavior and the role of regulatory frameworks in shaping their hedging properties would also enrich our understanding.

As financial markets continue their evolution toward sustainability, and as climate-related risks are becoming more important to portfolio performance, understanding the investment characteristics of green instruments grows more crucial. This thesis provides evidence that green finance represents not merely an ethical choice but a pragmatic one, offering investors tools to deal with uncertainty while aligning portfolios with environmental objectives. For policymakers seeking to mobilize capital toward sustainable development, these findings suggest that green instruments can attract investment on financial merit.

In conclusion, green bonds and renewable energy assets demonstrated credible hedging effectiveness during the COVID-19 crisis, maintaining stable risk-adjusted performance while traditional strategies faltered. As sustainable investing expands, these instruments warrant serious consideration in institutional and individual portfolios alike, not as substitutes for traditional diversification but as complements that enhance resilience in an uncertain world.

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