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SUSTAINABILITY VS. STABILITY: SHOULD CENTRAL BANKS INVEST IN GREEN BONDS?

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***Abstract**: Over the past few years, central banks have increasingly prioritized sustainable development policies, actively seeking ways to promote sustainability through their financial strategies. One potential approach is investing a portion of their foreign exchange reserves in green bonds, thereby supporting the financing of environmentally friendly projects. However, for green bonds to be considered suitable investments for central banks, they must satisfy key portfolio requirements - ensuring security, liquidity, and profitability. This research explores the viability of central banks allocating part of their reserves to green bonds, analyzing whether these investments align with the abovementioned necessary conditions. The aim of this research is to determine whether incorporating green bonds influences overall portfolio risk and enhances diversification while supporting the achievement of sustainable development goals. To address these considerations, portfolio optimization was conducted using Markowitz's model, incorporating traditional central bank investment assets such as government bonds, corporate bonds, stocks, gold, and green bonds. The findings suggest that adding green bonds to a central bank's portfolio has neither a significant impact on portfolio risk nor a notable effect on diversification. Moreover, the study reveals that portfolios containing green bonds exhibited similar responses to COVID-19 shocks as those without them, reinforcing the rationale for such investments. Ultimately, the results indicate that while green bonds do not contribute significantly to diversification, they also do not elevate portfolio risk. Therefore, central banks may consider investing in these instruments primarily as part of their commitment to social responsibility rather than for improving portfolio performance.*

***Keywords**: central banks, green bonds, portfolio diversification, foreign exchange reserves, Markowitz's model.*

***JEL Classification:** E58, E22, Q01, G11*

INTRODUCTION

The green economy and sustainable development have become increasingly significant in recent years, and require the involvement of an increasing number of institu-

tions that can contribute to green economy progress. Achieving the goals of sustainable growth within the green economy requires substantial financial resources. One of the key financing methods for green initiatives is the issuance of bonds to fund investments and cover costs associated with green projects. Given that these projects demand considerable capital, it is essential to attract investors willing to support such ventures. Among the institutions that can play a role in green financing are central banks, which have the potential to allocate a portion of their foreign exchange reserves to green bonds. This has led to the emergence of the concept of "green central banking," which integrates environmental risk considerations - including climate change risks that may influence both the short-term and long-term stability and development of the financial sector and the broader economy. However, for central banks to invest in green bonds, these financial instruments must satisfy specific requirements. In particular, they must be secure, liquid, and profitable while also contributing to portfolio diversification. By incorporating green bonds into their foreign exchange reserve portfolios, central banks can actively support green finance.

The aim of this research is to analyze the viability of central banks allocating part of their foreign exchange reserves to green bonds, evaluating whether these investments meet the fundamental criteria of safety, liquidity, and profitability. Additionally, the study examines the impact of green bonds on overall portfolio risk and diversification using Markowitz's portfolio optimization model. The research seeks to determine whether the inclusion of green bonds is justified within central bank portfolios and whether they serve as an effective instrument for sustainable finance while maintaining financial stability. Ultimately, it explores whether central banks should invest in green bonds primarily for financial returns or as part of their commitment to sustainability. The motive for undertaking this research stems from the growing importance of sustainable finance and the role of central banks in promoting environmental responsibility while maintaining financial stability.

Several hypotheses can be derived from the research objectives and main questions explored in the paper.

H1: Green bonds meet the fundamental investment criteria of central banks (safety, liquidity, and profitability). First hypothesis tests whether green bonds align with the primary requirements that central banks consider when managing their foreign exchange reserves.

H2: The inclusion of green bonds in central bank portfolios does not significantly impact overall portfolio risk. This examines whether adding green bonds alters portfolio volatility and risk exposure compared to traditional investment instruments.

H3: Green bonds do not provide significant diversification benefits in central bank portfolios. Third hypothesis investigates whether green bonds contribute to risk reduction through portfolio diversification or if their impact is negligible.

H4: Central banks invest in green bonds more for sustainability commitments rather than financial benefits. This hypothesis explores the motivation behind central banks' decisions to allocate reserves to green bonds - whether it is primarily a financial decision or a strategy for promoting sustainability and social responsibility.

The research provides an overview of the literature on green bonds, their characteristics and the inclusion of these bonds in the investment portfolio. An overview of the methodology, calculations and concrete conclusions about the justification of

central banks investing in green bonds is provided. The concluding remarks by the authors are defined in the final chapter.

LITERATURE OVERVIEW

The concept of the green economy and green finance has gained increasing relevance in recent years, largely driven by growing public awareness of environmental issues and sustainable development. In order to sustain the green economy and achieve its objectives, securing adequate financing is essential. As a result, an increasing number of countries and corporations are issuing green bonds to fund various projects related to the green economy.

Central banks are playing a more prominent role in these initiatives, as they are increasingly encouraged to purchase green bonds to support the expansion of green finance while simultaneously contributing to sustainable development. Given their responsibility for ensuring financial and macroeconomic stability, central banks cannot remain uninvolved in addressing climate and environmental risks (Dikau & Volz, 2018). Green bonds represent a relatively new financial instrument designed to support environmental initiatives, sustainable development, and innovative investment practices. These bonds function similarly to conventional bonds, as their creditworthiness is directly linked to the issuer's rating. However, there is no universally accepted definition of green bonds, making the commonly used description the most widely recognized. Their primary role is to finance projects that promote sustainability, such as renewable energy, water management, energy efficiency, bioenergy, and low-carbon transportation (Campiglio, 2015). The growing interest in green bonds extends to both investors and economic policymakers, with central banks emerging as key stakeholders in this evolving market. Like other investors, central banks are increasingly encouraged to integrate green bonds into their investment models (Schoenmaker, 2019). Investors in green bonds aim to generate a measurable positive environmental impact by funding companies engaged in credible green projects. Although the green bond market has been expanding, its overall size remains relatively small, with Europe accounting for 49% of total issuances. Corporations and financial institutions play a leading role in this market (Fatin, 2019).

By 2021, the value of the green bond market had reached USD 433.30 billion and it is widely anticipated that this market will continue to grow. As green bonds become more attractive to various investors, including central banks, it is crucial that they meet essential criteria related to risk, liquidity, and profitability. When evaluating green bond investments, central banks assess the issuer's credit risk profile to ensure credibility. However, as the green bond market is still in its early stages, concerns remain regarding pricing, liquidity, and diversification. (Carney, 2015) highlighted the critical role of central banks in fostering sustainable economic growth worldwide. A key initiative in this regard is the establishment of the Network for Greening the Financial System (NGFS), a platform that brings together approximately 75 central banks, regulatory authorities, and international financial institutions. The primary mission of the NGFS is to promote a coordinated approach to addressing climate-related risks within the global financial system. This initiative operates under the guidance of the Bank for International Settlements. The 2030 Agenda for Sustainable Development was introduced in 2015 with the goal of eradicating poverty and guiding the world

toward peace, prosperity, and equal opportunities for all while preserving the health of the planet. As part of this agenda, all UN Member States adopted 17 Sustainable Development Goals (SDGs), outlining a 15-year roadmap to achieve them. These goals cover a wide range of topics, including climate change mitigation, environmental conservation, responsible consumption and production, and more. According to (Knežević Kušljić, 2022) the importance of all stakeholders is crucial for the implementation and realization of the Agenda of the Sustainable Development Goals.

Central banks, international financial institutions, financial regulators, global investors, and commercial banks all play a vital role in the development of green finance. (Volz, 2017) emphasizes that central banks are central figures in managing and stabilizing financial systems, utilizing various financial instruments to advance sustainable finance. Consequently, their involvement in green finance is justified, with central banks being recognized as key stakeholders, particularly in emerging economies. In 2020, the Bank of England (BoE) became the first central bank to explicitly acknowledge the climate risks associated with its monetary portfolio. In response, the BoE began assessing climate-related financial risks and exploring appropriate risk management strategies. Following its lead, other central banks have increasingly integrated environmental concerns into their operations, recognizing that understanding the link between financial and economic activities and climate change is essential for advancing the green economy.

Central banks hold a crucial position in financial markets, primarily as investors managing foreign exchange reserves. When a central bank invests in green bonds, it signals confidence in these instruments as secure and high-quality investments, which, in turn, enhances the credibility and reputation of the green bond market. This added legitimacy plays a crucial role in strengthening the financial foundation of the green economy. There are two main ways for central banks to "green" their balance sheets: through their international reserve's portfolio and through monetary operations in domestic markets. However, despite their public endorsements of green finance, many central banks remain hesitant to engage directly in green bond investments. Given the substantial value of these reserves, careful consideration is necessary before making investment decisions. It is therefore essential to evaluate the feasibility of central banks allocating funds to green bonds.

Green bonds must fulfill certain conditions related to liquidity, security, and profitability for central banks to consider investing in them. In practice, this means that green bonds should hold high credit ratings, exhibit strong market liquidity, be easily tradable, and provide a reasonable return on investment. Bouyé, Klingebiel, & Ruiz, 2021 argue that ESG investments generally align with these conditions, making them suitable investment options for central banks. Ensuring investment security involves directing foreign exchange reserves toward financial instruments of the highest quality, typically those with investment-grade ratings and a well-established reputation for safety (Borio, Ebbesen, Galati, & Heath, 2008). Liquidity is another crucial requirement for foreign exchange reserves, necessitating investment in highly liquid instruments that can be quickly and easily converted into cash. Liquidity can be assessed in two dimensions: market liquidity and funding liquidity. A liquid instrument must be readily tradable at a price that aligns with market value, thereby minimizing price fluctuations. Additionally, liquidation costs should be minimal and incurred only during the transaction process. The

second aspect, funding liquidity, refers to an instrument's ability to provide short-term cash availability through asset sales, external financing, or collateralization. Profitability is also a key consideration, requiring central banks to invest in instruments that generate returns while maintaining adequate security and liquidity. Investment risk is equally important, as investors assess both potential risks and expected returns before making financial decisions (Bodie, Kane, & Marcus, 2014, p. 516).

The EU green bond market is increasingly attracting investor interest. However, the authors point out that green bonds are somewhat less liquid than traditional bonds, although their liquidity remained stable during the financial instability caused by the COVID-19 crisis in 2020. Based on these observations, the authors conclude that the green bond market does not show significant vulnerabilities (Mazzacurati, Paris, & Tsiotras, 2021).

The other group of authors observe a rising interest among central banks in green bond investments, asserting that sustainable development goals can be integrated into central banks' foreign exchange reserve management without compromising core objectives such as safety, liquidity, and profitability (Fender, McMorrow, Sahakyan, Zulaica, & Omar, 2019). Similarly, it is recognized that central banks are placing greater emphasis on sustainable growth, social responsibility, and environmental considerations, particularly in relation to well-diversified investment portfolios. However, they caution that central banks still primarily allocate investments to government bonds of stable economies, limiting the scope for green bond investments. They conclude that any green bond or ESG investment incorporated into a central bank's foreign exchange reserves should align with the institution's broader investment principles and standards applied to existing asset classes (Bouyé, Klingebiel, & Ruiz, 2021).

A study conducted by the Network for Greening the Financial System (Elderson & Mauderer, 2019) shows that when central banks engage in green investments, they set a precedent for other investors, thereby reducing both the risks associated with these instruments and potential reputational risks. This highlights the important role that central banks can play in fostering confidence in the green bond market and contributing to the broader transition toward sustainable finance.

Extensive research, particularly studies conducted by the Bank for International Settlements (BIS), has explored the role of green bonds in foreign exchange reserve portfolios. Researchers have determined that central banks can incorporate sustainability objectives into their governance policies without compromising fundamental principles such as security and return. Investment diversification is a crucial consideration for central banks. These researchers demonstrated that adding green bonds to a central bank's portfolio enhances diversification, thereby improving the risk-return ratio in a manner similar to conventional portfolios. The other researchers found that portfolios containing green bonds tend to outperform those composed solely of traditional bonds in terms of the risk-return ratio. The advantages of green bond investments stem from both increased yields and reduced volatility in most cases, supporting the conclusion that these instruments offer substantial investment benefits. Incorporating green bonds into reserve portfolios enhances diversification and improves risk-adjusted returns (Yingwei & Jie, 2022).

Beyond environmental benefits, the green economy generates positive social and economic impacts. Securing adequate funding sources and attracting investor interest in

green projects has been a critical concern during post-crisis recovery phases. Achieving these objectives requires collaboration and mutual benefits among investors, governments, financial markets, and other key stakeholders (Topić - Pavković, 2020).

As noted (Bilas, Bošnjak, & Franc, 2022) the global pandemic has demonstrated that certain social, health, economic, and other circumstances or phenomena are not always predictable. In times of crisis, a clear, transparent, efficient, and swift response is essential. The role and significance of global institutions are constantly assessed, but their effectiveness becomes most apparent during periods of crisis. Their responsibility in developing, coordinating, and implementing essential global measures and policies is more crucial than ever.

METHODOLOGY

To evaluate the impact of including green bonds in central bank portfolios, the analysis incorporated several financial instruments: government bonds (EG00 index), a corporate bond index (EB00 index), a green bond index (GRENIndex), the stock index of the European Monetary Union (SX5E Index), and gold (XAU_Currency). The dataset covered a period of nine years, spanning from 2011 to the end of 2021, with monthly data observations.

Strategic asset allocation frequently employs the well-established Markowitz methodology. Based on Markowitz's portfolio theory, investors evaluate various portfolios by analyzing expected returns and standard deviations within the framework of the indifference curve. Markowitz demonstrated that, for a given expected return and a specific set of securities, it is possible to construct an optimal portfolio that minimizes overall risk, as measured by portfolio variance and standard deviation. Achieving this optimization necessitates an understanding of the covariance and correlation among different asset combinations.

Mean-variance analysis provides a systematic approach to constructing asset portfolios that aim to maximize returns for a given risk level. It emphasizes that diversifying investments across multiple asset classes can effectively reduce risk compared to holding a single type of financial instrument. The Markowitz model, also referred to as mean-variance portfolio optimization, is widely utilized in portfolio management to optimize asset allocation decisions.

In this study, two distinct portfolios were constructed: one that included green bonds and another that excluded them. The optimization process involved computing monthly returns, standard deviations, and covariance, followed by determining the optimal portfolio composition based on these metrics.

Monthly returns of each instrument are calculated using the formula (Šoja, 2019), (Šoja & Senarathne, 2019) and (Bodie, Kane, & Marcus, 2014):

$$r_{it} = \ln\left(\frac{p_{it}}{p_{it-1}}\right)$$

Where r_{it} is the return of asset i in the portfolio and ln denotes the natural logarithm, p_{it} is the price (or the value of the index) at the period t and p_{it} – 1 is the price or value of an asset in the prior period (i.e. t – 1).

The standard deviation is calculated as shown below (Šoja, 2019).

Formula 1. Standard Deviation of the Return Series

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{j=1}^{n}\left(r_j - \bar{r}\right)^2}{N}}$$

In which: r_j is the value of *jth* point in the data set, $\bar{r}$ is the mean return in the return series and N is the number of observations.

Source: Šoja, T. (2019). Gold in investment portfolio from perspective of European investor. The European Journal Of Applied Economics, 16(1), pp. 41-58.

The covariance between any two assets in the portfolio is computed as follows (Levišauskait, 2010):

Formula 2. Covariance Between Two Assets in a Portfolio

$$\text{Covariance (A, B)} = \frac{\sum(r_A - \bar{r}_A)(r_B - \bar{r}_B)}{N}$$

Where r_A is the return of asset A and r_B is the return of asset B in the portfolio and $\bar{r}_A$ denotes the average return of asset A and $\bar{r}_B$ denotes the average return of asset B. N, as usual, is the number of observations.

Source: Levišauskait, K. (2010). Investment Analysis and Portfolio Management. LEONARDO DA VINCI Transfer of Innovation. Kaunas: Vytautas Magnus University

Covariance is essential in assessing the relationship between two assets, as it helps determine the direction of their movement relative to each other. A positive covariance indicates that the returns of both assets move in the same direction - when asset A's return exceeds its average (positive), asset B is also likely to experience positive returns, and vice versa. In contrast, a negative covariance suggests that the assets move in opposite directions - when asset A's return is above its average (positive), asset B's return is likely to be negative, and vice versa.

To calculate the correlation between assets A and B, one can employ the following method (Levišauskait, 2010).

Formula 3. Correlation Between Two Assets

$$\text{Correlation } (p) = \frac{Cov\ (A, B)}{\sigma_A \sigma_B}$$

Cov(A, B) is the covariance between asset A and asset B. σ_A and σ_B are the standard deviation of asset A and asset B.

Source: Ibid.

Expected returns of portfolios are calculated as follows (Levišauskait, 2010):

Formula 4 Expected Return of a Portfolio

$$E_{r(p)} = \sum_{i=1}^{n} W_1\, E_{i(r)} = W_1 E_{1(r)} + W_2 E_{2(r)} + \cdots + W_N E_{N(r)}$$

Where $E_{r(p)}$ is the expected return r on the portfolio p and W is the weight of asset i in the portfolio p.

Source: Ibid.

Empirical evidence

To construct the portfolio, five key instruments were selected, including commonly used indexes in reserve management and an index representing green bonds:

- **GRENIndex (Bloomberg Green Bond Index):** Represents green bonds denominated in EUR. This index serves as a well-structured benchmark for the green bond market and defines the available investment options for allocation decisions.
- **EG00Index:** Represents government bonds issued by EMU countries and denominated in EUR. The average duration of this index is approximately eight years.
- **EB00Index:** Represents EUR-denominated corporate bonds with an average duration of about four years. This index comprises issuers with high credit ratings.
- **SX5E (Euro Stoxx 50):** Represents equities in the European Union market, specifically an index of blue-chip stocks in the region.
- **Gold:** denominated in EUR.

For portfolio optimization, monthly data spanning from January 2011 to July 2022 were utilized. Using this dataset, the average return (as a measure of expected returns) was calculated for each instrument, along with the standard deviation, frequency, and Value at Risk (VaR). The complete dataset and results are presented in Table 1.

Table 1. Descriptive statistics

	EG00 Index	GRENIndex	SXS5	Gold	EB00
Mean	0,25%	0,03%	0,32%	0,51%	0,23%
StDev	1,35%	2,20%	4,82%	4,20%	1,21%
Freq<0	41,01%	46,04%	45,32%	47,48%	39,57%
Empirical VaR	-1,98%	-3,59%	-7,61%	-6,41%	-1,75%
Parametric CVaR	-1,98%	-3,13%	-6,94%	-5,24%	-1,71%
Empirical CVaR	-2,54%	-4,51%	-9,63%	-8,17%	-2,26%
Empirical CVaR	-2,59%	-5,41%	-10,31%	-7,70%	-3,09%

Source: Authors' calculations

Table 1 presents an overview of the average monthly returns for the entire observed period, highlighting that gold achieved the highest average return of 0.51%, while green bonds recorded the lowest, with an average monthly return of 0.03%. Among the asset classes, corporate bonds exhibited the lowest standard deviation, whereas the SX5E index displayed the highest volatility. When assessing risk through

Value at Risk (VaR), it is evident that equities and gold consistently demonstrate higher VaR across all risk types. Once the data is computed, portfolio optimization algorithms are employed while keeping the portfolio aligned with central bank principles, but also incorporating green bonds. To ensure compliance, certain limits are introduced regarding the share of each instrument within the portfolio.

The limits are:

- Green bonds can have a portfolio share of 0%-100% since we want to introduce this bond in the portfolio.
- Th e share of government bonds is determined to min 0% and a max of 100% since this is the main investment instrument for the central bank community.

The share of corporate bonds is fixed to min 10% and a max of 100%. The World Bank reports show that central banks invest up to 10% of their portfolio in corporate bonds (WB, 2021). The share of shares is fixed to a max of 5%. The World Bank report considers a very small amount in investment to shares, usually up to 5% (WB, 2021). The share of gold is fixed to a max of 6%. Empirical research usually confirms that the share of gold in the portfolio is useful and could be up to 6% (Šoja, 2019).

The limits imposed on the portfolio are designed in accordance with the rules set by central banks, taking into account the principles of safety, liquidity, and profitability in the investment process. These limits serve to mitigate risks associated with volatile assets such as gold and shares, while still maintaining a portion of these assets in the portfolio. In addition to these limits, it is assumed that the risk-free rate is 0% and short selling is prohibited. Once these constraints are in place, the algorithm is implemented with the objective of constructing a portfolio that minimizes risk, as measured by the standard deviation.

Table 2 presents the minimum variance portfolio, detailing the portfolio configuration with the lowest possible risk. It also includes the Sharpe ratio, which measures risk-adjusted returns, and the expected returns for the optimized portfolio.

Table 2. Portfolio composition and risk measures

	Portfolio with green bonds min risk	**A portfolio without green bonds**	**10% of green bonds**
Return	0,2510%	0,2520%	0,2312%
Risk	1,1391%	1,1391%	1,1521%
Sharpe	0,22	0,22	0,20
EG00 Index	32,23%	32,17%	33,46%
GRENIndex	0,48%	0,00%	10,00%
SXS5	0,00%	0,00%	0,00%
Gold	5,48%	5,49%	5,16%
EB00	61,82%	62,33%	51,38%
Risk measures			
Freq<0	37,41%	36,69%	37,41%
Parametric VaR	-1,58%	-1,58%	-1,63%
Empirical VaR	-1,19%	-1,17%	-1,43%

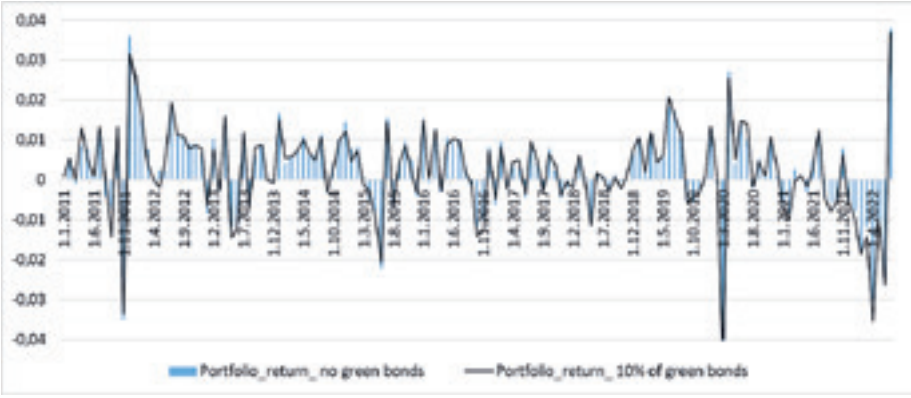
Parametric CVaR	-2,05%	-2,05%	-2,11%
Empirical CVaR	-2,69%	-2,69%	-2,76%

Source: Authors' calculations

Table 2 presents the composition and performance of three portfolios: one including green bonds, one excluding them, and another with a 10% allocation to green bonds. In the first portfolio, green bonds make up only 0.47% of the total allocation, as the optimization algorithm prioritizes minimizing risk.

The second portfolio illustrates the structure and performance of a portfolio without green bonds, while the third portfolio incorporates a 10% share of green bonds. The results indicate that all three portfolios exhibit similar expected monthly returns, ranging between 0.23% and 0.25%, with comparable risk levels, as measured by standard deviation. These findings suggest that including green bonds does not lead to a higher return relative to risk. The Sharpe ratio, which evaluates the return per unit of total risk beyond the risk-free rate, is slightly higher for the portfolio including green bonds. However, this implies that the return-to-risk ratio is marginally lower compared to a portfolio without green bonds. Since central banks prioritize risk management in their investment strategies, Value at Risk (VaR) measures were calculated for all three portfolios. The findings show that a portfolio with a 10% green bond allocation carries slightly higher risk, but the difference is not significant when compared to other portfolios. As a result, it can be concluded that green bonds neither increase overall risk nor significantly enhance returns. Additionally, the analysis suggests that green bonds do not provide substantial diversification benefits. While they marginally improve the Sharpe ratio, they do not lead to higher expected returns or lower portfolio risk. Ultimately, incorporating green bonds into a central bank's portfolio results in slightly lower expected returns and a marginally higher risk compared to a conventional portfolio. Figure 1 illustrates the returns of the portfolios with and without green bonds, further visualizing their performance differences.

Figure 1. The returns of the portfolios with and without green



Source: Authors' calculations

The findings suggest that both portfolios - with and without green bonds, demonstrate similar returns, even during the COVID-19 crisis in 2020. This indicates that the inclusion of green bonds does not contribute to higher volatility in the portfolio compared to one that excludes them. The results confirm that green bonds do not introduce additional risk, reinforcing their stability as an investment option within a central bank's portfolio.

RESULTS AND DISCUSSION

The results of the research provide valuable insights into the implications of incorporating green bonds into central bank portfolios. By applying Markowitz's portfolio optimization model, the study assesses the impact of green bonds on portfolio risk, diversification, and overall financial performance. The results indicate that green bonds meet the fundamental investment criteria of central banks, but do not significantly enhance portfolio diversification or risk-adjusted returns. The results show that the inclusion of green bonds in a central bank's reserve portfolio does not lead to a substantial change in overall portfolio risk. The risk levels, measured through standard deviation and Value at Risk (VaR), remain relatively unchanged between portfolios that include green bonds and those that do not. Additionally, the Sharpe ratio analysis suggests that green bonds do not provide a superior risk-return tradeoff compared to traditional investments such as government or corporate bonds.

The key insights align with previous studies, such as Fender et al. (2020), which concluded that green bonds exhibit similar financial characteristics to conventional bonds in terms of returns and volatility. Similarly, research by Yingwei & Li (2022) found that while green bonds contribute to sustainability objectives, they do not necessarily outperform traditional bonds in terms of financial returns. One of the key objectives of this research was to determine whether green bonds contribute to portfolio diversification for central banks. The findings indicate that the diversification benefits of green bonds are marginal at best. Although diversification generally helps mitigate risk by spreading exposure across different asset classes, green bonds demonstrate a high correlation with existing fixed-income assets in central bank portfolios, limiting their effectiveness as a diversification tool.

These results contrast with some previous studies, such as Fender et al. (2019), which suggested that green bonds may improve portfolio diversification under certain conditions. However, the present research suggests that in a central bank's context - where investment decisions are primarily guided by safety and liquidity concerns, the diversification advantage of green bonds remains limited.

A significant aspect of this research is its analysis of green bond performance during economic crises, particularly the COVID-19 pandemic. The research outcomes reveal that portfolios containing green bonds responded similarly to market shocks as those without them. This suggests that green bonds do not introduce additional risk during financial downturns, reinforcing their stability as an investment option. These findings are in line with Mazzacurati et al. (2021), who noted that green bonds remained relatively liquid and stable during the COVID-19 crisis. Their study also pointed out that green bonds tend to be slightly less liquid than traditional government bonds, which central banks heavily rely on for their foreign exchange reserves.

The outcomes of this study have significant policy and investment implications

for central banks considering green bond investments. Since green bonds do not appear to significantly impact risk-adjusted returns or portfolio diversification, their primary justification within a central bank's portfolio is likely based on sustainability commitments rather than financial performance. This supports the argument made by Bouyé et al. (2021), who emphasized that central banks may integrate sustainability considerations into their investment frameworks without compromising key objectives of safety and liquidity. Also, the role of central banks in setting a precedent for private investors should not be overlooked. By investing in green bonds, central banks can help strengthen market confidence in sustainable finance, potentially leading to greater issuance and liquidity in the green bond market over time.

CONCLUSION

The research aimed to explore the feasibility and implications of central banks incorporating green bonds into their foreign exchange reserve portfolios. Based on this objective, several key hypotheses were formulated. One of the central hypotheses was that green bonds meet the fundamental investment criteria of central banks, which include safety, liquidity, and profitability. Given that central banks prioritize investments that ensure security and stability, this hypothesis tested whether green bonds could be considered viable reserve assets. The findings indicate that green bonds generally align with these criteria, as they exhibit sufficient creditworthiness and a risk profile comparable to traditional investment-grade bonds. While green bonds may have slightly lower liquidity than government bonds, they remain tradeable assets suitable for reserve portfolios. Their profitability, however, is similar to that of conventional bonds, with no significant financial outperformance. Another key hypothesis examined whether the inclusion of green bonds in central bank portfolios significantly impacts overall portfolio risk. Since central banks manage reserves with a strong focus on risk minimization, it was essential to evaluate whether adding green bonds would alter portfolio volatility. The research results show that green bonds do not introduce additional risks, as evidenced by standard deviation and Value at Risk (VaR) measures, which remained stable across portfolio variations. This suggests that central banks can incorporate green bonds without increasing their overall risk exposure. The study also investigated whether green bonds provide significant diversification benefits. A well-diversified portfolio is expected to reduce risk by including assets with low correlation. However, the findings suggest that green bonds are highly correlated with other fixed-income assets, limiting their effectiveness as a diversification tool. Unlike gold or equities, which tend to have lower correlations with bonds, green bonds do not significantly contribute to risk reduction within a central bank's portfolio. This challenges some previous studies that suggested green bonds could enhance diversification under specific conditions.

Furthermore, the research explored whether central banks invest in green bonds primarily for sustainability commitments rather than financial benefits. The results suggest that the primary motivation for including green bonds in central bank portfolios is policy-driven rather than financial. Green bonds neither enhance returns nor reduce portfolio risk significantly, reinforcing the idea that their inclusion serves as part of a broader strategy to support sustainable finance. This aligns with global trends, where central banks, such as the European Central Bank (ECB) and the Bank of England (BoE), have incorporated green finance into their monetary policy frameworks.

By investing in green bonds, central banks not only contribute to sustainability efforts but also set an example for private investors, helping to strengthen market confidence in the green bond sector.

The research makes several important contributions to both academic literature and policy discussions on sustainable finance and central banking. First, it provides empirical evidence on the role of green bonds in central bank reserve management by systematically evaluating their risk, return, and diversification potential. Using Markowitz's portfolio optimization model, the study offers a data-driven approach to assessing the impact of green bonds on portfolio performance. Additionally, the study highlights the evolving role of central banks in green finance, emphasizing their influence in shaping financial markets and promoting sustainable investments. Unlike private investors, central banks operate under different constraints and objectives, making their approach to green bonds unique. While previous research suggested that green bonds could improve diversification, this study finds that in the context of central banking, their diversification benefits are limited.

The policy implications of this research are significant. The findings support the inclusion of green bonds in central bank reserves, not necessarily for financial advantages, but for their role in promoting sustainability and fostering confidence in the green finance sector. Central banks, by investing in green bonds, can influence private investors and contribute to the expansion of sustainable finance. However, policymakers should recognize that green bonds alone do not enhance financial performance and should be included as part of a balanced investment strategy that aligns with central bank objectives of stability and liquidity.

While this research provides empirical evidence on the role of green bonds in central bank reserve portfolios, it has some limitations that warrant further research. One significant limitation is the reliance on Markowitz's portfolio optimization model, which, while widely used, does not capture all aspects of central bank reserve management, such as dynamic investment strategies and real-world constraints on asset allocation. Future studies could explore alternative models, such as stochastic optimization or multi-objective portfolio approaches, to gain a more comprehensive understanding of how green bonds fit into central bank reserves. Another limitation is that the study focuses on a specific timeframe, covering the period from 2011 to 2021. While this period includes significant financial events, such as the COVID-19 pandemic, longer-term studies incorporating more economic cycles could provide deeper insights into the stability and performance of green bonds under different macroeconomic conditions.

In conclusion, the research confirms that while green bonds align with central bank investment principles in terms of safety, liquidity, and profitability, they do not offer substantial financial advantages in terms of returns or diversification. Their inclusion in central bank portfolios is driven primarily by sustainability goals rather than financial optimization. The study contributes to ongoing policy debates on green finance by providing empirical evidence on the real-world implications of green bond investments for central banks. It highlights the need for careful policy design to ensure that sustainability objectives are met without compromising monetary and financial stability.

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