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Sustainable Finance and Climate Risk: Evaluating the Role of Green Energy Assets

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ABSTRACT :

Climate change is being viewed as a systemic cause of financial risk, which impacts on assets, portfolio allocation, and global financial system stability. Green assets and sustainable finance have received increased interest in this regard among policymakers and investors. But it is also not known whether popular Green Exchange-traded funds (ETFs) are actually indicative of climate and market risks hedging, or whether they act more like traditional high-beta equity exposures. The thesis answers that question, which is accomplished by studying the financial performance and the risk nature of four large clean-energy ETFs around the world (ICLN, TAN, CNRG and FAN) between the years 2018-2024, and through the analysis of their association with climate policy uncertainty. The empirical study will use daily data of 1,522 trading days. The prices of ETFs, worldwide and upcoming equity standard (ACWI, EEM, BKF) and gold (GLD) are transformed to log returns and consequently excess returns with the help of the 3-month U.S Treasury bill rate (DTB3) as the proxy of the riskless rate. The China Climate Policy Uncertainty (CCPU) index, the news-based measure of climate policy risk, is used to measure climate policy risk on one of the major emitting nations in the world. The empirical approach is premeditatedly straightforward and narrow. To describe the risk-return profile and co-movements of green ETFs and equity benchmarks and gold, first, the descriptive statistics and correlation matrices are employed. Second, the hedge and safe-haven regressions, according to Baur and Lucey (2010) and Baur and McDermott (2010), are estimated to determine whether the green ETFs hedge global and emerging equity markets or are safe havens in times of hard economic times. Third, regression of markets using a market model augmented with the standardised CCPU index is implemented to determine the independent impact of daily policy uncertainty in climate policy on the excess returns of green ETFs when global equity movements have been adjusted. The findings indicate that clean-energy ETF are significantly more unstable than the world stock standard and display stronger negative tail returns, its risk-adjusted performance is mostly lower than ACWI and in a few instances even lower than gold. The correlations and betas show the four green ETFs move in a very close pattern and fully committed to both global and emerging equity markets but gold has weak correlations with equities. As a result, green ETFs can never be considered as hedges or safe havens in the conventional sense of the term: the betas of the funds are positive and meaningful during normal conditions as well as during the state of crisis. Further, the statistically significant impact of CCPU index on excess returns that ICLN has is not significant even after considering the global market risk. Generally speaking, the results imply that clean-energy ETFs are currently functioning as pro-cyclical and high-beta equity sector exposures as opposed to being natural hedges against climate-related financial risk.

KEYWORDS: clean-energy ETFs; climate risk; climate policy uncertainty; hedge and safe haven; sustainable finance

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Abbreviations

BRIC	Brazil, Russia, India and China
BRICS	Brazil, Russia, India, China and South Africa
CAPM	Capital Asset Pricing Model
CCPU	China Climate Policy Uncertainty index
CPU	Climate Policy Uncertainty
CRFR	Climate-related financial risk
DTB3	3-month U.S. Treasury bill rate
ESG	Environmental, Social and Governance
ETF	Exchange-traded fund
EU	European Union
FRED	Federal Reserve Economic Data
GDP	Gross Domestic Product
HAC	Heteroskedasticity and Autocorrelation Consistent
IEA	International Energy Agency
IFC	International Finance Corporation
IMF	International Monetary Fund
MPT	Modern Portfolio Theory
NGFS	Network for Greening the Financial System
OLS	Ordinary Least Squares
SDG	Sustainable Development Goal
SPDR	Standard & Poor's Depository Receipt
SRI	Socially Responsible Investment
SSRN	Social Science Research Network
UNCTAD	United Nations Conference on Trade and Development
Y02	Y02 patent classification

1 INTRODUCTION

1.1 Background and Motivation

Climate change has been one of the 21st-century challenges that has destabilized ecosystems, put the health of human beings at risk, and led to unstable world economies. Extreme weather, regulatory developments, and carbon costs are climate risks that are increasing pressure on financial institutions to alter their approach to investments (International Monetary Fund, 2022). These threats not only sway the ecology and standards of living but also change the principles of the financial market and the economic growth of the entire world.

Sustainable finance is emerging as a key trend nowadays. It suggests that the environmental, social, and governance (ESG) issues will be included in making financial decisions (United Nations Environment Programme Finance Initiative, 2023). The purpose of sustainable finance is to make sure that the financial systems, in their capital flows, can generate returns and generate economic growth, inclusive and environmentally friendly. The use of the language here partly overlaps with sustainable finance, green finance, and climate finance refer to similar, but not the same spheres (Green Finance Platform, 2016).

Sustainable finance is concerned with the consideration of ESG in investment decisions, which would encourage capital investments into sustainable economic activity in the long term. Such environmental factors include climate change mitigation and adaptation, conservation of biodiversity, pollution, and the circular economy. These social aspects involve inequality, inclusivity, job relations, human rights, and also development of society. The aspect of governance involves the shapes and forms of both governmental and non-governmental organizations, including compensation of the executives, the relations with the workers, and the responsibility before the administration (European Commission, 2023). Together, these dimensions will allow financial decisions to be considered in terms of broader societal and environment-related consequences.

Governments and supranational institutions have responded by establishing composite structures to hasten the process of switching to low-carbon economies at the level of policy. Considerably, the European Green Deal, which was initiated in 2019, is to turn the European Union into a resource-efficient economy with a view of having climate neutrality by 2050 and 50 percent reduction by 2030. The plan will enhance clean energy, green infrastructure, and innovation and provide socially equitable transition (European Commission, 2019). All these activities emphasize the extent to which the need to pay more attention to the inclusion of the climate action into the financial and economic frameworks is appreciated.

The climate risks have taken more up to date concern as regards the value of financial assets. These risks may be typically divided into physical risks - due to the financial implications of weather-associated climate conditions and the long-term physical changes, and transition risks, which are associated with the shifts of the policies, technology, and trends in the preferences of the market operating in the low-carbon economy (Albanese et al., 2024). Based on the empirical evidence, transition risks may be particularly large in the case of financial markets since they can bring a direct effect to the price of assets and investor sentiment and portfolio allocation in the long term (Bua et al., 2024).

The financial regulators also noted that the financial stability can be jeopardized by the mispricing of the climate risk. When asset prices fail to capture the risks associated with climate, then capital could be mispriced, and a swift change in the risk aversion of investors could cause a market correction. Even with the increasing environmental awareness, there are still a lot of investors who are reluctant to implement the use of climate factors systematically. This can also be explained by, among other factors, the non-harmonisation of the performance indicators and difficulties in approaching climate risks through methodology (Zhang, 2022). As such, there is a current trend of increased need of strong evidence on how sustainable investments will perform in terms of economy.

Among the themes that have gained more significance is the spotlight of green energy holdings such as renewable energy stocks, clean energy exchange-traded funds (ETF) and low-carbon technologies in the investment portfolio of global investors. The International Energy Agency (2023) reports that the investment in clean energy technologies in the world has exceeded USD 1.7 trillion in 2023, almost twice as much as is invested in fossil fuels. This change is one of the indications of climate imperatives and economic opportunities. In this context, special attention can be given to such emerging markets as BRICS countries (Brazil, Russia, India, China, and South Africa). These are economies that have individual difficulties in their energy transitions because of rapid industrialization and large populations with high carbon footprints. Meanwhile, they also have great potential to impact global decarbonization by policy innovation, technological development, and infrastructure building (United Nations Conference on Trade and Development, 2023).

1.2 Problem Statement

Climate change is a systemic risk to world financial markets which influences the prices of assets, investment flows and the general volatility of the market. The increasing empirical evidence demonstrates that financial asset valuations and investor behaviour may be influenced by risks associated with climate, both physical and transition and policy-based (Dutta et al., 2023). Although the effects of climate risk on conventional wealth like oil, gold and broad equity indices have been investigated in several studies, very little has been said about the financial performance of the green energy resources. This is a gap to note because the investment in renewable energy is on the rise and green energy assets are becoming a part of sustainable finance.

Although this is on the rise, the question that remains unclear is whether green assets are capable of providing competitive and stable returns and significant means of protection against climate-related shocks. The available literature suggests that certain green instruments might have partial hedging advantages under some circumstances, although

the findings are inconclusive and conditional on a particular asset type and market environment (Cepni et al., 2022). In addition, the empirical data pertains to the developed markets in the majority of cases. There is a little understanding of the behavior of the green energy assets in the emerging market, where climate exposure, regulatory frameworks, and financial market structures vary considerably from those of the advanced economies (United Nations Conference on Trade and Development, 2023).

At the same time, the broader policy discussion reveals that there is a need to understand how climate risks can be monitored in the assets prices in the economic regions that are most central to the energy transition process in the world such as the BRICS economies. In these conditions, where there is no good evidence of the risk-return projectile and diversification properties of the green energy resources, investors and policy makers struggle to establish their role in the building of climate resistant portfolios and to sustainable development. This is bridged in this thesis by the emphasis in the interpretation of the relationship between the risks associated with climate and the developed and emerging market environment in the financial performance of the green energy assets.

1.3 Purpose of the Study

This study aims to analyse the financial performance of green energy assets—specifically, global clean energy exchange-traded funds (ETFs)—in the broader context of sustainable finance and climate risk. Although climate-related risks are increasingly recognised as systemic for the stability of the global financial system (Dutta et al., 2023), the contribution of green energy ETFs to managing these risks is not yet well understood. Previous research has focused mainly on traditional commodities (such as oil and gold) and developed equity markets, leaving a gap in knowledge regarding the performance of green assets in emerging economies (United Nations Conference on Trade and Development, 2023).

The purpose of this thesis is to assess whether green energy ETFs can provide competitive returns and diversification benefits, and whether they exhibit any hedging or safe-haven characteristics under climate-related uncertainty. The study pays particular attention to differences between developed and emerging market benchmarks, with a special focus on BRICS-related indices, in order to capture variations in institutional quality, policy environments and market structures.

By focusing on a limited set of green energy ETFs and a small number of empirical tests, the study seeks to provide clear and interpretable evidence on how climate-related risks are reflected in the risk–return profile of green energy assets, rather than attempting to cover many different mechanisms and models.

1.4 Research Questions

According to the purpose above, the thesis will answer the following research questions:

1. How do the risk-return properties (returns, volatility and basic hedging properties) of green energy ETFs compare to the broad equity market benchmarks?
2. What is the relationship between climate policy risk and excess returns of green energy ETFs?
3. Are the risk and return characteristics of green energy ETFs different when compared and evaluated against emerging market benchmarks, compared to a global benchmark of the developed markets?

1.5 Significance and Contribution of the Study

The thesis concerns itself with sustainable finance and climate risk as it looks into the financial nature of the green energy assets, i.e., returns, volatility, and simple hedging

behaviour, in a climate uncertainty. Although the possibility of using green assets as diversifiers or partial hedges has been reported in the past (Cepni et al., 2022 ; Dutta et al., 2023), the majority of the sources of this information concern developed markets. It is through the incorporation of emerging markets and the specific emphasis on the BRICS-related indices that the current study can become a source of new evidence of how the concept of climate risk is incorporated into the efficiency of green energy ETFs in the areas that at the same time are vulnerable to climate change and at the same time are at the center of the global energy transition (United Nations Conference on Trade and Development, 2023).

The research would have consequences to various categories of stakeholders. To scholars, it connects the findings of climate finance and asset pricing to the particular case of green energy ETFs and offers empirical findings of a straightforward and comparatively simple modelling technique. To investors, the results will give an insight into whether green energy ETFs can help in diversifying the portfolio and their sensitivity to climate policy risk. The findings provide the policymakers and regulators with a basis of evidence that can be used in discussions of how financial markets price the climate-related risks, particularly in those economies with low capital inflow into the clean energy (International Energy Agency, 2023).

Generally, the study assists in closing the gap between the theory and practice by giving empirical evidence on the use of green energy assets to deal with climatic related financial risks in both developed and emerging markets.

1.6 Thesis Structure

This thesis is structured into six chapters, which form a consistent discourse of the financial performance of green energy assets that are exposed to climate risk, and especially on the emerging markets.

Chapter 1 presents the topic of the research, the background of the topic in terms of sustainable finance and climate related financial risks, as well as the statement of the problem, purpose, research questions and contributions of the study.

Chapter 2 sets a literature review on the current knowledge on sustainable finance, climate risk, financial performance of green energy assets and their possible hedging and safe-haven features. It also addresses the context of the emerging markets and BRICS economies in particular and determines the gaps in the research.

Chapter 3 establishes the theoretical framework based on modern portfolio theory, the Capital Asset Pricing Model and climate finance and policy uncertainty frameworks. It builds on these three testable hypotheses concerning climate policy risk, market environment and risk-return profile of green energy ETFs.

Chapter 4 explains the research design, such as the choice of green energy ETFs and benchmark indexes, the generation of the measurement of the risk and the measurement of risk, the climate policy uncertainty index and the empirical models that will be applied to examine the risk-return characteristics and the effect of climate policy risk.

The empirical results are shown in chapter 5. It presents the descriptive statistics and the risk-return profile of the chosen assets and further discusses the results of market-model regressions and climate policy risk regressions of green energy ETFs upon the different benchmarks.

Chapter 6 provides a summary of the key findings concerning the research questions and hypotheses, the theoretical implications, and practical implications of the study to investors and policymakers, the limitations of the study and future recommendations on green energy asset and climate-related financial risks research.

2 LITERATURE REVIEW AND HYPOTHESES

2.1 Sustainable Finance and Climate Risk: An Overview

The concept of sustainable finance has become a topic of discussion in scholarly studies and in the policy agenda more generally, as the issue of environmental, social, and governance (ESG) factors becoming paramount to long-term financial stability gains greater acceptance. Sustainable finance is fundamentally understood as the incorporation of the ESG aspects into the process of making investment decisions with an aim to make the distribution of capital consistent with the objectives of sustainable development (Edmans and Kacperczyk, 2022). In this context, the climate risk has become especially topical, with climate change being perceived not only as an environmental problem but also as a systemic financial risk (International Monetary Fund, 2022).

Climate-related risks, including physical (as in extreme weather events) and transition-related (as in policy changes, technology disruptiveness), have been highlighted by the Network for Greening the Financial System (Network for Greening the Financial System, 2021) as sources of a destabilizing financial environment through their impact on asset prices, credit risk, and market volatility. These are not limited risks in individual sectors, but economy-wide risks, so of much interest to the policymakers, regulators and investors.

The new dimension of the traditional risk-return trade-off of investors is introduced by climate risk. At the moment, they should consider how more stringent climate regulation and rapid technological development will influence their contact with carbon-intensive industries or reliance on fossil fuel (Battiston et al., 2017). At the same time, such green energy instruments as renewable energy equities, green bonds and clean technology funds are also regarded as the means that might not only result in the monetary compensations, but also contribute to the achievement of the goals associated with climate (Dutta et al., 2023).

This trend is strengthened by institutional reports. According to the International Energy Agency (2023), investment in clean energy technologies in the world has exceeded the amount of money invested in the fossil fuel, which is characteristic of the policy and investor demand. Equally, the United Nations Conference on Trade and Development (United Nations Conference on Trade and Development, 2023) emphasizes the fact that the sustainable investment flows are on the increase, yet, they are not evenly spread across the regions, as emerging markets, in particular, the BRICS economies, lag developed countries in terms of attracting green finance.

The field of literature is not unanimous on how green assets can be utilised in dealing with climate-related financial risk. There is a claim that green assets can be used as hedge or even safe haven in response to climate risk (Cepni et al., 2022), but also some studies give mixed or situation-specific results (Reboredo, 2018). Further, the focus of most empirical studies has been on the developed markets. The information on the emerging markets is still relatively poor, and this fact implies that the financial performance of green assets in these environment remains poorly understood.

To conclude, sustainable finance and climate risk are closely interconnected. The literature points to the urgency of learning how the risk posed by climate change can influence the pricing of assets and the performance of portfolios, and it is especially in the markets susceptible to climate change and in the markets that play a decisive role in the global energy transition. This forms the basis of analyzing the financial performance of green energy assets in more detail in the subsequent sections.

2.2 Financial Performance of Green Energy Assets

Following Chapter 1, in which sustainable finance was presented as one of the possible answers to the issue of systemic climate risk, this chapter will discuss financial performance of green energy assets in various market and policy environments. The available literature brings out opportunities and challenges. Green assets can be attractive and have the advantages of diversification on the one hand. Conversely, their

volatility and hedging attributes seem to be context dependent and this is more apparent in developing and emerging markets including the BRICS economies.

Empirical research indicates that the risk of climate is a major factor that affects the returns and volatility of green investments. Dutta, Bouri, Rothovius, and Uddin (2023) show that the risks of transition and physical climate influence the performance of green stocks and bonds, and are more sensitive to climatic awareness moments. Reboredo (2018) discovers that the co-movement patterns of green bonds and conventional financial markets are different, which opens potential for diversification. Nevertheless, Rasoulinezhad and Taghizadeh Hesary (2022) warn that volatility in renewable energy projects may necessitate policy incentives and quality institutions, so the volatility will be high in less stable economies.

Another topic that the literature addresses is whether the green assets would be hedges or safe havens. Cepni, Demirer, and Rognone (2022) give support that some of the green assets are capable of hedging risks related to climate, but the hedging effectiveness varies among the assets classes. Broadstock and Cheng (2019) demonstrate that the correlation between green and conventional (black) bond benchmarks is time dependent and affected by macroeconomic conditions and thereby conclude that green bonds can offer diversification benefits but not safe haven-like properties all the time.

The bulk of the existing empirical evidence has been on developed markets, and the emerging economies have little research on them. The more recent studies of climate risk in international corporate bond markets demonstrate that the information flows that capture climate-related information, in form of media based indicators, are linked to the changes that occur in the price of the corporate bonds, and these results suggest that the perceived climate risk may affect the financing conditions (Benkraiem, Dimic, Piljak, Swinkels, & Vulcanovic, 2025). Meanwhile, it is also mentioned that BRICS economies have problems trying to attract green capital, in part because they are perceived as having more risks and worse institutional environments than many developed economies (UNCTAD, 2023; IEA, 2023).

Another factor of financial performance is technological innovation. Gao, Guo, and Wei (2023) prove that the development of renewable energy efficiency, as well as battery storage, influences the dynamic correlation between green bonds and other financial markets. The IEA (2023) also emphasizes that the returns of investments in clean energy are becoming more and more dependent on technological development, and innovation is an essential factor in the work of assets.

Altogether, it is written in literature that the assets of green energy may be competitive on the basis of returns and diversification benefits, but volatility and hedging nature of these assets greatly rely on the context of the market. The latest research on climate risk in bond markets has augmented familiarity on the application of climate information in assets prices (Benkraiem, Dimic, Piljak, Swinkels, and Vulcanovic, 2025), though little systematic data has been documented to prove the financial outcomes of green energy assets in the BRICS economies. That is why both technological innovation and the climate risk should be taken into account comparing developed and emerging markets. This is the requirement which is met by the present research since it examines the green power resources in these diverse market conditions.

2.3 Hedging and Safe Haven Properties of Green Assets

The ability of green assets to serve as credible hedges or safe havens is one of the main questions of sustainable finance. Climate risk is systemic, and it has an impact on the pricing of assets in financial markets, as explained in Chapter 1. It is against this backdrop that there is an increased interest among investors in instruments that can be used to protect portfolios in case of an increase in uncertainty. The green assets (renewable energy equities, green bonds) have been investigated as the possible means to this end. But the available information about their hedging and safe-haven properties is still inconclusive, and seems to be highly market-specific. The hedge is usually considered as an asset which is negatively correlated with another asset or even market in normal circumstances and a safe haven is an asset which does not lose value or moves out of line during a time of intense stress in the market (Baur and Lucey, 2010).

Recent research says that renewable energy resources and green bonds may or may not be effective hedges, safe havens, but the data is inconsistent. Cepni, Demirer and Rognone (2022) suggest that the introduction of green assets into a portfolio can help reduce the risks of climate, albeit based on the asset type and time period. Another finding of the authors Azad, Hayat and Ahmed (2023) is that renewable energy securities have weak hedging and safe-haven properties when there is uncertainty among the global economic policy, and generally are less effective in this property than more established securities, such as gold. Khamis and Aassouli (2023) learn in the review of the system that in some regimes and perceptions of investors, green bonds can be useful in the diversification process but are safe-haven assets.

More traditional safe-haven investments, such as gold and U.S. Treasuries, are more durable. However, Broadstock and Cheng (2019) demonstrate that the relationship between the green and conventional (black) bond benchmarks is time-related and relies on the macroeconomic variables, which means that the green bonds might be used as complementary, but not alternative, to the traditional hedges.

Limited evidence exists of the emerging markets, but studies have shown that the institutional quality and policy credibility play a major role in governing whether green assets can be hedges. According to Benkraiem, Dimic, Piljak, Swinkels, and Vulcanovic (2025), corporate bond prices are determined by climate risk information, meaning that the spread of information and investor sentiment will be key to determining which markets are safe havens in less developed markets. It emphasizes the need to analyze the BRICS economies where the exposure to climate is the greatest and financial health is poorer.

The literature generally suggests that the green assets can be useful in the context of diversification, and it can also have some hedging benefits against the climate risks, but the safe-haven nature of the green assets is not universal across markets and highly market-specific. That is why the developed and emerging markets need to be comparatively

analyzed as is the case in this thesis, in elucidating the role of green assets in addressing the portfolio risk in climate uncertain conditions.

2.4 Emerging Markets and the BRICS Context

As discussed in Chapter 1, the global energy transformation will require huge flow of capital to renewable energy sources and low-carbon technologies. The developed economies have made a long stride in mobilising the green finance, however, the emerging economies particularly the BRICS countries (Brazil, Russia, India, China and South Africa) have their share to stake in the future of sustainable finance. These countries are already a considerable part of the global energy consumption and emissions, but there are some problems with attracting and introducing green capital successfully.

The BRICS economies put together represent more than forty percent of the global population and a large portion of the global GDP. They are increasing their energy needs and their areas of transition will be key in dictating how successful climate objectives in the world will be. According to the International Energy Agency (2023), the investment in clean energy in emerging economies is still lower than in developed economies, however, these economies are one of the most sensitive to climate change. In the same vein, UNCTAD (2023) indicates that despite the upward trend in foreign direct investment in sustainable energy ventures, the allocation of the flows has been unequal: BRICS nations continue to experience challenges in the ability to attract enough funds in comparison to most of the developed economies.

The operations of green assets in BRICS economies have a number of institutional barriers that limit their operations. Weaker institutional structures, less predictable and stable policy environments, less deep financial markets, and greater perceived sovereign risk are common in these countries. The insufficiency of regulatory backing and ineffective capital markets also restrict the provision of green finance in most developing nations (Rasoulinezhad & Taghizadeh-Hesary, 2022). The flow of information and the

mood of investors are also significant in the asset pricing process. The international corporate bond markets reveal that the externalities related to climate risks, represented by media coverage, can have a significant impact on the bond prices, highlighting that an emerging economy can be exposed to external shocks as well as narratives concerning climate risk (Benkraiem, Dimic, Piljak, Swinkels, and Vulcanovic, 2025).

However, with the significance of these challenges, there are also opportunities that are presented by the emerging markets. Financial technology (fintech) has been revealed to accelerate the effectiveness of green finance in BRICS economies in terms of facilitating projects to be easier to fund and lower the cost of transactions to contribute to the green economic growth (Bel Hadj Miled, 2025). They also believe that, the policies that are intended to facilitate green financing in the emerging economies should be applied together with efficient risk management programs (Okeke, Bakare, and Achumie, 2024). All these facts suggest that the problem of the structural barriers can be resolved with the help of institutional innovation and the implementation of the new technologies.

According to the literature, despite the fact that BRICS economies dominate the world energy transition, they continue to have significant challenges in mobilising green finance and guaranteeing the stability of green assets. The institutional weaknesses, policy uncertainty and information asymmetry limit their capability to draw sustainable investment. Simultaneously, opportunities at the same time exist in green-finance strengthening through the introduction of fintech and supportive policy frameworks in these markets. It is against this background that the current research is useful as it presents an analytical evaluation of financial performance of the green energy assets in BRICS economies, compares the findings with the results in developed markets and evaluates the representations of climate risk and technological advances to the results.

2.5 Technological Advancements in Renewable Energy

As stressed in Chapter 1, the energy transformation in the world is not just a financial issue, but also a technological one. The output of green energy assets is directly linked

to the rate of innovation in renewable technologies and such issues directly affect the structure of costs, efficiency, and investor confidence. The recent technological advances in solar, wind, battery storage, and smart grids have changed the economics of renewable energy by making green assets more competitive to the conventional energy investments.

The last ten years have been characterized by a fast rise in the efficiency of solar photovoltaic (PV) and wind turbines, making the levelized cost of electricity (LCOE) very low. The International Energy Agency (2023) states that the utility-scale solar costs decreased by over 80 percent since 2010, and the wind power costs dropped by almost 60 percent. These have increased the profitability of renewable energy initiatives and boosted the financial results of green equities and bonds related to them. As Kyei, Boateng, and Frimpong (2025) emphasize, renewable energy technologies are the key to the realization of Sustainable Development Goals because they do not only help reduce emissions but also enhance economic feasibility.

The problem of intermittency has been solved through the development of battery technology and energy storage systems, which has been identified as one of the major constraints of renewables. Gao, Guo, and Wei (2023) demonstrate that the correlation between green bonds and larger financial markets is reinforced by the fact that renewable projects appear more stable and less risky because of the process of improving storage capacity and integrating smart grids. Also, Cavus (2025) says intelligent grid technologies such as microgrids and distributed generation contribute to the reliability of green energy systems, which increases investor confidence in green assets.

Cost reduction is only one of the impacts of technological innovation on the future of assets and the fluctuations of prices. With a more developed renewable technology, the green assets will not rely on subsidies and policies, thereby reducing the risk of regulation. Simultaneously, the innovations in efficiency and storage open new

opportunities of investment and push the capital flows towards green finance. This is especially vital to emerging markets, where institutional weaknesses can be compensated through technological adoption and foreign investment can be attracted (UNCTAD, 2023).

The literature indicates that the technological advancements are a conclusive factor in determining the financial performance of the green energy assets. Innovation makes renewables more competitive, increases their efficiency, and reliability, decreasing the risk and increasing their competitiveness. In the context of BRICS economies, where institutional and policy issues continue to be a problem, technological advancement is providing a channel through which investor confidence can be enhanced and the shift to sustainable finance can be expedited. The background of this thesis also refers to these technological advances and the empirical analysis is premised on the climate policy risk and the performance of green energy ETFs in terms of their financial performance.

2.6 Identified Gaps in Existing Research

Although the literature on green finance and renewable energy assets is growing, they cannot eliminate several critical gaps that make the topic stimulate the modern studies. Global energy change that is discussed in Chapter 1 should be mobilised not only on large scale but on a more insightful manner in relation to the impact of climate risk, technological innovation and institutional structures on the performance of green assets. The existing study is quite helpful, but it is not spread evenly over the areas, assets and approaches to the research methods.

The majority of empirical research on the performance of the green assets is carried out in developed economies, especially, on the United States and Europe (Reboredo, 2018; Dutta et al., 2023). Although such evidence is informative, there are dynamics of emerging markets that are not adequately reflected in such evidence, including institutional quality, policy uncertainty and sovereign risk that may vary significantly. According to reports by the World Bank (2024), the United Nations Conference on Trade

and Development (2023), the amount of green investment in the emerging markets is insignificantly low compared to what is required. Nevertheless, the systematic academic data on green assets performance in BRICS economies, particularly, with regard to their financial performance and their position in investor portfolios, remains rather limited.

Although other scholars, such as Cepni, Demirer, and Rognone (2022), Benkraem, Dimic, Piljak, Swinkels, and Vulcanovic (2025) have examined the role of climate risk perception on financial markets, much of the literature now considers green assets to be homogeneous instruments. There has been a paucity of research regarding the effect in comparison to the volatility, returns, and hedging characteristics of green energy property with the various types of climate risk, including physical, transition, and informational, in the emerging economies.

To a certain degree, the significance of technological advances in the sphere of renewable energy and storage is noticed to result in the reduction of costs and efficiency growth (IEA, 2023; Gao et al., 2023). However, there are few studies that directly relate those innovations to financial performance of green assets, especially in such situation, when the adoption of technologies is extremely biased, as it is the case of BRICS. This creates a gap in knowledge that regards the interaction between innovation and institutional and market structure in its impact on asset pricing.

The available empirical evidence has a high concentration on short time span, one country or a limited number of asset classes. According to BloombergNEF (2025), the investments are growing in renewable energy in developing economies, however, it also mentions that there are gaps and inconsistencies in the information that complicate the process of making solid comparisons. The same issue is noted by the Bank of International Settlements that highlights the limitation of empirical modelling due to the scanty data on standardised climate financing (Fareed et al., 2024). The latter restrictions indicate that longer time series, more cross-country comparisons and multi-asset models are needed to gain deeper insights into green asset performance.

To conclude, the literature has significantly contributed to knowledge bases of green finance, but has also shown to have several gaps: (i) limited evidence on BRICS and other developing markets, (ii) little evidence on the types of climate risk that are captured in asset prices, (iii) a methodological weakness of gap in data and small research design, and (iv) a weakness in the literature created by the relatively small number of studies. These gaps need to be closed so as to have a more holistic picture of how the green energy assets perform in the climate risk environment, especially the economies that are most in need of energy transition. This thesis seeks to fill in the gaps by providing a comparative empirical research of the green energy assets financial performance of BRICS and developed markets with particular focus on how the risks of climate are captured in the returns and risk profiles.

2.7 Research Hypotheses

Depending on the gaps that have been presented in Section 2.6, this thesis draws up three hypotheses that associate climate risk, green energy exchange-traded funds (ETFs), and various market settings.

H1: There exists a strong impact of climate policy risk on the performance of green energy ETFs.

According to the previous studies, it is stated that the risks of climate, both physical and transition related are becoming more visible in the financial markets and they already start to be considered in the models of asset-pricing and risk management. A news-based Climate Policy Uncertainty (CPU) index represents climate risk in this thesis. H1 will be concerned with the significance of this index with excess returns of global green energy ETFs. Practically, H1 can be tested by testing the relationship between the CPU index and ETF excess returns in a return regression which also controls the world equity market.

H2: The ETFs of green energy offer certain diversification advantages over equity benchmarks, but without the effects of safe-havens as some traditional investments like gold.

According to the literature, the idea of green assets has the potential to enhance portfolio diversification, yet the capacity to serve as safe haven or hedges during a time of market stress is controversial. Empirical data and results usually indicate that the green assets exhibit positive, although occasional moderate, relationships with the overall equity indices, and their downside protection is not as strong as the performance of the traditional safe-haven assets like gold. H2 shows this tradeoff by arguing that under normal conditions, green energy ETFs are able to decrease the risk of the overall portfolio in a diversified state, but does not offer the downside protection offered by standard safe-haven assets. The hypothesis is evaluated by descriptive measures of risk-return, correlations as well as simple market-model regressions against global equity standards.

H3: The financial performance of green energy ETFs and risk features has no significant differences compared to the emerging-market benchmark and developed-market benchmark.

The literature of green finance is largely concentrated in developed economies, despite the fact that the rising proportion of the global energy consumption and clean-energy investment is concentrated in emerging markets. There is also a disparity in institutional quality and policy uncertainty and sovereign risk by region and these factors could influence the behavior of green assets in a portfolio. H3 thus postulates that the risk and returns of green energy ETFs are different when measured against the emerging market standard as compared to a developed-market standard. This is tested through the basic performance measures (volatility and Sharpe ratios), correlations and market betas of green ETFs as compared to the various benchmark indices.

3 THEORETICAL FRAMEWORK

3.1 Risk-Return Theory and Portfolio Diversification

The concept of risk and return lies at the heart of modern finance and provides the foundation for evaluating the role of green energy assets in sustainable investment portfolios. As established in Chapter 1, the growing urgency of climate change has introduced new dimensions of financial risk, while Chapter 2 highlighted the mixed evidence on the performance of green assets relative to conventional energy investments. To situate these debates within a theoretical framework, this section draws on Modern Portfolio Theory (MPT) and subsequent developments in risk-return analysis.

Harry Markowitz's seminal work (1952) introduced the principle that investors can optimize expected returns for a given level of risk through diversification. By combining assets with imperfectly correlated returns, investors can reduce portfolio variance without necessarily sacrificing expected returns. This insight remains central to contemporary portfolio management and is particularly relevant when considering the integration of renewable energy assets into traditional portfolios dominated by fossil fuel companies. If green energy assets exhibit low or negative correlation with conventional energy or broader market indices, they may enhance portfolio efficiency by shifting the efficient frontier outward (Markowitz, 1952; Elton & Gruber, 1997).

The Capital Asset Pricing Model (CAPM), developed by Sharpe (1964) and Lintner (1965), further formalized the relationship between risk and return by distinguishing between systematic and unsystematic risk. In this framework, only systematic risk--captured by an asset's beta--should be priced in equilibrium. For green energy assets, this raises the question of whether climate-related risks are adequately reflected in market betas, or whether they represent an additional, underpriced source of systematic risk (Pastor et al., 2021). This theoretical lens is particularly important given the evidence, reviewed in

Chapter 2, that climate policy shocks and technological disruptions can significantly affect asset volatility.

Portfolio diversification theory also intersects with the emerging literature on safe-haven and hedging properties of alternative assets. Traditionally, gold has been viewed as a hedge against market downturns (Baur & Lucey, 2010). Recent studies suggest that renewable energy equities and green bonds may play a similar role under conditions of heightened climate risk or fossil fuel price volatility (Henriques & Sadorsky, 2008; Reboledo, 2014). This perspective aligns with the problem statement outlined in Chapter 1, which emphasized the need to evaluate whether green assets can mitigate climate-related financial risks in both developed and emerging markets.

In sum, risk-return theory and portfolio diversification provide a robust framework for analyzing the financial performance of green energy assets. They not only justify the empirical investigation of correlations, volatility, and risk-adjusted returns but also connect directly to the hypotheses formulated in Chapter 2.7. By situating green energy assets within the broader tradition of portfolio theory, this study seeks to determine whether they can enhance diversification benefits while addressing the systemic risks posed by climate change.

3.2 ESG and Sustainable Investment Models

Furthering the premises of the risk-return theory in Section 3.1, integrating the Environmental, Social, and Governance (ESG) factors in investment decision-making is a significant development in contemporary finance. As mentioned in Chapter 1, climate change has come with systemic risks that are mostly invisible to the traditional financial models. Chapter 2 has also established that, as much as green energy assets perform well in terms of financial performance, their sustainability can be best assessed based on the frameworks that explicitly consider sustainability aspects. ESG models particularly provide this lens, with corporate behavior and environmental responsibility having a connection to long-term financial performance.

The ESG investing tradition is a development of the broader tradition of socially responsible investment (SRI) that placed an emphasis on ethical screening of investments. However, not everything of ESG frameworks is an exclusionary practice, which pursues approaches to evaluating how firms manage environmental threats, social obligations, and governance systems (Friede et al., 2015). The change is reflective of the recognition of the reality that sustainability factors are financially material and they can influence risk and return. To give an example, firms with a good environmental policy may be less susceptible to a regulatory penalty or a reputation boycott, but firms with a good governance system may be reporting lower agency expenses and increased efficiency in the utilization of capital (Clark et al., 2015).

Theoretically, the ESG models align with the stakeholder theory which suggests that companies are able to create value not only to the shareholders but also to the employees, the customers, the communities and the environment (Freeman, 2022). The latter broadened definition of value is particularly relevant to the situation with renewable energy companies, which often tend to fall into the area of technological innovation, environmental activism and advocacy of states. This aspect of sustainable companies that they can attain competitive advantage by balancing between financial and non-financial objectives is further augmented by the triple bottom line model that aims at people, the planet, and profitability (Elkington, 1998).

The economic usefulness of the integration of ESG is empirically demonstrated. The meta-analysis of over 2,000 studies shows that the ESG performance has a positive correlation with the financial returns, particularly within the long term (Friede et al., 2015). This, when applied to the green energy assets would mean that investors who use ESG criteria would not only get better returns risk-adjusted, but less exposure to climate risks as well. Moreover, the recent scholarly evidence on the sustainability investing in the equilibrium demonstrates that the preference of investors towards sustainability can change the price of assets and reduce the future expected gains of the assets that are

perceived as brown and hike the valuation of assets that are perceived as green (Lubos Pastor et al., 2021).

In conclusion, ESG and sustainable investment models can be used to support the hypotheses that are outlined in Chapter 2.7 since they provide them with a theoretical basis. They also offer the answer as to why green energy assets may turn out to be attractive in the long-term, as to why green energy may be considered as hedges against climate risk, and as to whether policy and governance structures are factors that decisively affect their financial results. ESG frameworks fill the gap between the conventional portfolio theory and climate finance by adding the issue of sustainability to the basic analysis of finances.

3.3 Climate Finance and Policy Uncertainty Frameworks

Climate finance can be defined as the development of capital to finance both mitigation and adaptation initiatives in reaction to climate change. As explained in Chapters 1 and 2, the move towards the low-carbon economy will demand serious investment into renewable energy and smart infrastructure. Nevertheless, the success of these investments is strongly determined by policy uncertainty as it can change the perceptions of risks, capital flows and the value of assets.

When governments give signals of committing to climate but fail to implement or do it, this leads to policy uncertainty to investors. This uncertainty is associated with both transition risks (e.g., carbon pricing, emission caps, subsidies), as well as physical risks (e.g., disaster resilience funding). Gavriilidis (2021) created the Climate Policy Uncertainty (CPU) Index, which is a quantitative metric of climate uncertainty and it has been demonstrated, affects asset volatility and the cost of sovereign borrowing (Guo et al., 2025).

In theoretical terms, climate finance can be said to be focused on radical uncertainty when it comes to future climate policies and how they affect the financial system. Ryan-

Collins (2019) suggests the precautionary approach to financial regulation, and he says that the conventional risk decision models do not take into account the systemic climate risks. It corresponds to the literature on climate-related financial risk (CRFR) that underlines the significance of central banks and regulators to introduce climate scenarios in stress-testing models (Battiston et al., 2017).

Empirical research demonstrates that policy uncertainty raises the cost of capital to governments and firms especially in the emerging markets where the institutional frameworks are challenged (Guo et al., 2025). On the other hand, well-defined and plausible weather policies, including feed-in tariffs, tax credits, and disclosure, decrease the uncertainty, as well as promote the investment in the green energy assets (Bhandary et al., 2021). This relationship is directly related to the following hypotheses of Chapter 2.7: the performance of green energy assets can be higher in the market with consistent and supportive climate policies, and in an environment of policy uncertainty, their volatility is more likely to increase.

4 METHODOLOGY

4.1 Research Design

My thesis is a quantitative time-series research approach where I study the hypothesis that the global clean-energy exchange-traded funds (ETFs) provide (i) hedging and safe-haven properties over equity benchmarks and gold, and (ii) reactions to climate policy-uncertainties.

As in normal financial econometrics, the test is applied to the daily log returns and excess returns, rather than to levels of prices, when the prices absorb new information at a high rate as in the efficient market hypothesis.

The empirical undertaking is subdivided into two large blocks:

Hedging and safe-havens: Establish, as Baur and Lucey (2010) and Baur and McDermott (2010) have, that green energy ETFs hedge world and emerging equity markets and that they are safe havens in a stressed equity market.

Climate policy uncertainty (CPU) analysis: Establish the sensitivity of excess returns of green ETFs to a news-based China Climate Policy Uncertainty (CCPU) index, in a simple market-model regression model that is ultimately augmented with CCPU (Ma et al., 2023).

The two basic tests, on which the empirical contribution is built, are (1) hedge/safe-haven regressions and (2) CPU-augmented return regressions, although the current report of descriptive statistics is supposed to provide an overview of risk-return profiles and correlations.

4.2 Data Sources and Sample Selection

4.2.1 Green energy assets

The empirical study will involve four clean-energy ETFs that are highly traded:

- ICLN - iShares Global Clean Energy fund.

- TAN - Invesco Solar ETF
- CNRG- SPDR S&P Kensho Clean Power ETF.
- FAN - First Trust Global Wind Energy ETF.

The reason behind the selection of these funds is:

1. Thematic purity and coverage: they collectively cover global clean energy, solar, broad clean power and wind, which contrasts with the thesis focus on the green energy assets instead of the broader ESG indices.
2. Liquidity and data availability: their assets under management are relatively large and their daily price histories are long, which is significant in the time-series analysis.
3. Application in recent academic literature: all four ETFs (ICLN, TAN, CNRG, FAN) are already used in recent risk, connectedness, or hedging property of clean-energy asset studies, which is why they are suitable and comparable.
4. Therefore, the sample of four ETFs is purposely small: it focuses on the most popular and liquid clean-energy ETFs that have already become the standard in the literature and does not attempting to encompass all the small thematic funds.

The adjusted closing prices of the stock are downloaded daily in CSV format as a public financial data provider like Yahoo Finance. Empirical studies of energy and clean-energy ETFs have been widely done using these sources, which have been used in peer-reviewed studies of empirical finance.

4.2.2 Benchmarks and safe-haven asset

The benchmarks that would be employed to measure performance and hedging properties are as follows:

- Global equity standard: ACWI- iShares MSCI ACWI ETF (representative of the global stock market).

- Benchmark of the emerging market: EEM iShares MSCI Emerging Markets ETF (proxy of emerging equity markets).
- BRIC robustness benchmark: BKF - iShares MSCI BRIC ETF, the only robustness benchmark because it is a more focused proxy of BRIC exposure (Brazil, Russia, India, China).

These are the global and emerging markets exposure standards that are typical in the literature on the clean-energy and traditional energy ETF studies.

To have the traditional safe-haven comparison, the thesis employs:

- GLD SPDR Gold Shares ETF is a proxy of gold that is a traditional hedge and a safe-haven asset in the empirical literature.

The same data provider of green ETFs provides the daily adjusted closing prices of ACWI, EEM, BKF and GLD so that there is consistency.

4.2.3 Climate policy uncertainty index (CCPU)

The China Climate Policy Uncertainty (CCPU) index, which is constructed by Ma et al. (2023) as the proxy of climate policy risk. This index:

- is trained on the MacBERT deep-learning language model on 1.7 million articles of six major Chinese newspapers,
- is published at daily frequency since 2000,
- is ambiguous on climate-related policies (e.g. emissions regulation, carbon pricing, renewable subsidies).

Calendar date merging of daily CCPU values at the national level with daily ETF and benchmark return panel is done. The daily index removes the previously mentioned issue of frequency mismatch and is in line with other recent works that utilize CCPU in daily or high-frequency applications.

China is selected due to its and because China is a significant emitter and a clean-energy deployment leader and shifts in the Chinese climate policy position can impact the clean-energy markets on the globe and investor confidence.

4.2.4 Risk-free rate

The 3-month U.S. Treasury bill secondary market rate (FRED series DTB3), which is available on the Federal Reserve Economic Data (FRED) database, is used as the proxy of the risk-free rate with a frequency of daily. A direct way of responding to the previous remark about frequency is to use a daily risk-free series, which is normal practice in excess-return asset-pricing tests.

4.2.5 Sample period and alignment

The sample period is defined as the maximum period that meets the following conditions:

- all four green ETFs
- ACWI, EEM and GLD
- the daily CCPU index
- the daily DTB3 risk-free rate

Upon matching through trading day and eliminating days on which values in the key variables are missing, the final main sample is 2018-2024 (the start date varies based on the dates of the listing of the ETFs) and includes about 1522 observations per series per trading day. All series are downloaded in CSV format first, followed by combining them into one dataset using a spreadsheet and statistical software.

4.3 Variables and Indicators of Financial Performance

4.3.1 Dependent variables

1. Daily log returns

The log returns on each asset (i) in a day are calculated as

$$r_{i,t} = \ln(P_{i,t}) - \ln(P_{i,t-1}), \quad (1)$$

where $P_{i,t}$ is the **adjusted closing price** of asset i on day t . The reason why log returns are so much employed in empirical finance is that they are time-additive as well as they are very similar to simple returns when returns are small (Fama, 1970).

2. Excess returns

Excess returns will be defined as:

$$r_{i,t}^e = r_{i,t} - r_{f,t}, \quad (2)$$

Where $r_{f,t}$ is the daily riskless rate of DTB3. The over analysis of returns is also aligned with the asset-pricing models where the risk-free rate is the point of reference (Fama, 1970).

3. Risk-adjusted performance indicators (for descriptive comparison)

- **Sharpe ratio:**

$$Sharpe_i = \frac{\overline{r_i^e}}{\sigma(r_i^e)} \quad (3)$$

where $\overline{r_i^e}$ is the mean excess return.

Market beta: regression coefficient of ETF excess returns on ACWI excess returns.

These are some actions that give a summary overview of the risk-return profile of green ETFs, benchmarks and gold prior to actualizing the key regressions.

4.3.2 Explanatory variables

1. Market and regional factors

- $r_{m,t}^e$: excess on ACWI (global market factor).
- $r_{em,t}^e$: excess return on EEM (emerging-markets factor), which is applied in a different set of hedge/safe-haven regressions.
- Gold: excess of GLD that is added as an extra asset in descriptive comparisons and a benchmark safe-haven asset.

- China_CCPU_t : uncertainty index of the general climate policy of China daily, unit variance and normalised to zero mean (Ma et al., 2023).

4.4 Analytical Models

4.4.1 Descriptive statistics and correlations

The following are reported on all ETFs and benchmarks:

- mean and standard deviation of returns and excess returns daily.
- minimum and maximum returns
- skewness and kurtosis (to determine fat tails)
- Pearson correlations of green ETFs, ACWI, EEM, and GLD.

These statistics provide a first consideration of diversification potential and distributional properties that may be used to compute hedging and safe-haven tests.

4.4.2 Hedge regressions

In order to test the fact that the green energy ETFs are hedges against the global markets or emerging markets, the following regression is estimated on each of the two ETFs i :

$$r_{i,t}^e = \alpha_i + \beta_i r_{m,t}^e + \varepsilon_{i,t}, \quad (4)$$

where $r_{m,t}^e$ is the over performance of ACWI or EEM. According to Baur and Lucey (2010), an asset is considered to be hedged in case the average correlation, to the market, is negative or zero (Baur and Lucey, 2010).

- If $\beta_i \approx 0$ and the value is statistically insignificant means that ETF i is a hedge..
- If $\beta_i < 0$, it is a strong hedge.
- Larger positive β_i the higher the systematic risk, and the less the hedging power.

The approximated β_i can be also taken as a hedge ratio and indicates the degree of the market exposure which is calibrated in an ETF position.

The same regression of gold (GLD) is also being operated as a benchmark hedge asset to help to interpret the performance of the green ETFs through the hedging of the green ETFs versus a conventional safe haven.

4.4.3 Safe-haven regressions

- To test the hypothesis that green ETF are safe havens in the worst equity market crashes, the hedge regression is further generalized by adding a crisis interaction term (Baur and McDermott, 2010):
- To start with, consider a crisis dummy, which is determined by the global equity benchmark:
- calculate empirical 5th percentile $q_{0.05}$ of ACWI daily returns;

$$D_t^{crisis} = \begin{cases} 1 & \text{if } r_{m,t} \leq q_{0.05} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

The safe-haven regression is:

$$r_{i,t}^e = \alpha_i + \beta_i r_{m,t}^e + \gamma_i (D_t^{crisis} \times r_{m,t}^e) + \varepsilon_{i,t}. \quad (6)$$

Interpretation:

- On **normal days** ($D_t^{crisis} = 0$), the slope is β_i .
- On **crisis days** ($D_t^{crisis} = 1$), the slope becomes $\beta_i + \gamma_i$.

According to Baur and Lucey (2010), a hedge has a correlation (or beta) with the market which is zero or negative on average, and a safe haven is a investment which has a zero (or negative) beta in the times of crises (Baur and McDermott, 2010).

Thus, $\beta_i + \gamma_i$ is the **effective "crisis beta"**.

- If $\beta_i + \gamma_i \leq 0$ and not significantly positive, ETF ipossesses a safe-haven properties (it does not move with the crashing market).
- If $\beta_i + \gamma_i > 0$ and significant, ETF idoes is not a safe haven.

Gold (GLD) is once more to be added in this regression as a reference safe-haven.

4.4.4 Climate policy uncertainty regressions

A CPU-augmented market model is estimated in order to study the impact of the uncertainty in climate policy on the performance of green ETFs:

$$r_{i,t}^e = \alpha_i + \beta_i r_{m,t}^e + \delta_i \text{CCPU}_t^* + \varepsilon_{i,t}, \quad (7)$$

where:

- $r_{m,t}^e$ is the ACWI excess return,
- CCPU_t^* is the standardised CCPU index,
- δ_i measures the sensitivity of ETF i 's excess returns to climate policy uncertainty, controlling for global market movements.

Interpretation:

- If $\delta_i < 0$: higher climate policy uncertainty is associated with **lower** excess returns on the green ETF (policy uncertainty is perceived as a risk).
- If $\delta_i > 0$: higher uncertainty is associated with **higher** excess returns, e.g. if markets expect future supportive climate policies or speculative flows into green assets.

The model applies the framework of climate-uncertainty of Gavriilidis (2021) and the CCPU index of Ma et al. (2023), which demonstrates that uncertainty in climate policies could have an impact on the prices and volatility of assets.

4.4.5 Estimation and standard errors

Ordinary least squares (OLS) estimations on daily excess returns are used to estimate all hedge, safe-haven and climate policy uncertainty regressions. Daily financial returns are usually heteroskedastic and autocorrelated, and this attribute may cause bias in the normal OLS standard errors and draw erroneous conclusions. In this regard, the thesis indicates the use of newey-west heteroskedasticity- and autocorrelation-consistent (HAC) standard error of all regression coefficients (Newey and West, 1987).

The diagnostics of each of the models are as follows:

- Estimated coefficients $(\alpha_i, \beta_i, \gamma_i, \delta_i)$

- Newey–West HAC robust t-statistics and p-values
- Coefficient of determination (R^2 and adjusted R^2)
- Number of observations used in the estimation

Using HAC robust errors is standard practice in empirical asset-pricing and climate-finance research when working with high-frequency financial data, because it allows valid statistical inference under general forms of time-varying volatility and serial correlation in the residuals.

4.5 Limitations of the Methodology

Major weaknesses about this simplified methodology include:

- Single-country climate risk proxy: CCPU indicates the uncertainty in climate policy in China, and not the world. Nevertheless, China is the central figure in terms of clean energy and emissions, which is why it can be taken as a leading indicator.
- Omitted macro controls: none of the macroeconomic variables (e.g. inflation, exchange rates) are added, hence there is a possibility of omitted-variable bias.
- Sector concentration: green ETFs are all clean-energy oriented and can be highly correlated with one another; the findings cannot be generalized to all ESG or green investments.
- Minimalized volatility modelling: The volatility is not modelled using GARCH, but it considers the expected returns hedging, safe-haven and CPU effects.

In spite of those constraints, the methodology is coherent and focused: it directly addresses the research questions by making two fundamentally empirical tests (hedge/safe-haven and CPU sensitivity) and resorts to the data and indices that are already existing in the sustainable-finance literature.

5 EMPIRICAL ANALYSIS

The chapter provides the empirical evidence regarding the financial performance of the green energy exchange-traded funds (ETFs) in the climate risk setting. Daily data between 2018 and 2024 is analyzed, with a smaller sample (1,522 days of trading) used, limited to common data on the same sample of 1,522 days where all variables are available simultaneously:

- four clean energy ETFs: ICLN, TAN, CNRG, FAN,
- equity indexes: ACWI (global), EEM (emerging), BKF (BRIC),
- GLD as a conventional safe-haven asset,
- the (daily) risk-free rate (DTB3), and
- the China Climate Policy Uncertainty (CCPU) index.

Each asset is calculated to get its daily log returns and converts into excess returns by deducting daily risk-free rate. The empirical work is based on the Chapter 4 approach and is concerned with two fundamental tests:

1. Green ETFs on safe-havens and hedge behaviour of green ETFs;
2. Climate policy uncertainty (CCPU) sensitivity of green ETF excess returns.

5.1 Descriptive Statistics and Risk-Adjusted Performance

Table 1 gives the descriptive statistics of the daily excess returns of the common sample (N = 1,522). It presents the mean, standard deviation, minimum and maximum returns, skewness and excess of kurtosis of every asset.

Table 1 Descriptive statistics of daily excess returns (2018–2024)

(Excess return = log return – daily risk-free rate)

	<i>ICLN_e</i>	<i>TAN_e</i>	<i>CNRG_e</i>	<i>FAN_e</i>	<i>ACWI_e</i>	<i>EEM_e</i>	<i>BKF_e</i>	<i>GLD_e</i>
	x	x	x	x	x	x	x	x
Mean	0.0001	0.0003	0.0003	0.0001	0.0002	-0.0001	0.0001	0.0004

Median	-0.0002	0.0002	0.0005	0.0001	0.0007	0.0005	0.0002	0.0006
Standard Deviation	0.0196	0.0272	0.0225	0.0148	0.0122	0.0138	0.0152	0.0094
Sample Variance	0.0004	0.0007	0.0005	0.0002	0.0001	0.0002	0.0002	0.0001
Kurtosis	5.912	3.671	3.567	9.041	14.039	11.555	7.499	2.741
Skewness	-0.3664	0.1295	-0.2076	0.5364	-1.0120	-0.8510	0.1886	0.3479
Minimum	-0.1371	0.1754	-0.1414	0.1234	-0.1190	-0.1333	0.1161	0.0552
Maximum	0.1080	0.1324	0.1163	0.0986	0.0782	0.0774	0.1245	0.0474
Count	1522	1522	1522	1522	1522	1522	1522	1522

Volatility: all the four green ETFs have higher volatility compared to the global equity index ACWI (std. dev. \approx 1.22%). TAN is the most volatile (2.72%) and then CNRG, ICLN and FAN.

Downside risk: minimum daily returns of the green ETFs are lower than those of ACWI, which means that the funds have greater drawdowns on stress days.

Non-normality: the skewness of all series is negative, and all majority of the series are strongly skewed in negative kurtosis, particularly ACWI, EEM and FAN, which confirms the existence of fat tail and asymmetric downside risk, characteristic of financial returns data.

Table 2 Sharpe ratios of daily excess returns (2018–2024)

<i>Asset</i>	<i>Mean</i>	<i>Std. dev.</i>	<i>Daily Sharpe</i>	<i>Annualized Sharpe</i>
ICLN	0.0001	0.019597	0.0052	0.0831
TAN	0.0003	0.027219	0.0094	0.1493
CNRG	0.0003	0.022465	0.0144	0.2288
FAN	0.0001	0.014794	0.0045	0.0716
ACWI	0.0002	0.012212	0.0189	0.3006
EEM	-0.0001	0.013787	-0.0052	-0.0818
BKF	-0.0001	0.015178	-0.0094	-0.1494
GLD	0.0004	0.009388	0.0423	0.6714

GLD has the most risk-adjusted performance (annualized Sharpe \approx 0.67). ACWI has a medium-sized positive Sharpe ratio (\approx 0.30). CNRG and TAN have the highest Sharpe

ratios of the green ETF and ICLN and FAN present weaker risk-adjusted performance. The benchmarks of emerging-market EEM and BKF have negative Sharpe ratios implying poor performance on a risk-adjusted basis within this timeframe.

Overall, green ETFs are risky, equity-like investments that perform averagely on risk-adjusted performance.

5.2 Correlations and Market Integration

Table 5.3 reports the correlation matrix of daily excess returns. These correlations were computed on the same sample.

Table 3 Correlation matrix of daily excess returns

	<i>ICLN</i>	<i>TAN</i>	<i>CNRG</i>	<i>FAN</i>	<i>ACWI</i>	<i>BKF</i>	<i>EEM</i>	<i>GLD</i>
<i>ICLN</i>	1	0.871	0.919	0.812	0.749	0.679	0.714	0.128
<i>TAN</i>	0.871	1	0.919	0.665	0.638	0.601	0.618	0.109
<i>CNRG</i>	0.919	0.919	1	0.752	0.706	0.593	0.656	0.186
<i>FAN</i>	0.812	0.665	0.752	1	0.779	0.65	0.71	0.157
<i>ACWI</i>	0.749	0.638	0.706	0.779	1	0.802	0.876	0.106
<i>BKF</i>	0.679	0.601	0.593	0.65	0.802	1	0.952	0.143
<i>EEM</i>	0.714	0.618	0.656	0.71	0.876	0.952	1	0.167
<i>GLD</i>	0.128	0.109	0.186	0.157	0.106	0.143	0.167	1

High correlations between green ETFs (high correlation of 0.80 or more) imply that ICLN, TAN, CNRG and FAN do not provide much diversification within the clean-energy theme. There are high correlations to ACWI, EEM and BKF as well, and it means that green ETFs are tightly linked to both global and emerging equity markets.

All equity assets are highly negatively correlated with gold (GLD) \approx 0.11-0.19), which is in line with the diversification nature of this asset.

This correlation pattern already indicates that green ETFs cannot be effective hedge, or even safe haven, against equity risk. This is then formally tested in the following section.

5.3 Hedge and Safe-Haven Properties

The regression models that are described in Chapter 4 are used to evaluate Hedging and safe-haven behaviour. OLS estimations of all the regressions are done on the same common sample (N = 1,522) with Newey-West heteroskedasticity- and autocorrelation-consistent standard errors.

5.3.1 Hedge regressions

Hedging behaviour is examined using the standard market model:

$$r_{i,t}^e = \alpha_i + \beta_i ACWI_{ext} + \varepsilon_{i,t}, \quad (8)$$

where $r_{i,t}^e$ is the excess return of asset i , and $ACWI_{ext}$ is the excess return on ACWI. Following Baur and Lucey (2010), an asset is considered a **hedge** if its beta is zero or negative on average.

Table 4 Hedge regressions vs ACWI (daily excess returns)

<i>Asset</i>	<i>N</i>	<i>Beta_ACWI</i>	<i>SE_beta</i>	<i>t_beta</i>	<i>p_beta</i>	<i>R²</i>	<i>Adj. R²</i>
<i>ICLN</i>	1522	1.151	0.034	34.292	0	0.514	0.514
<i>TAN</i>	1522	1.411	0.051	27.673	0	0.401	0.401
<i>CNRG</i>	1522	1.299	0.049	26.664	0	0.499	0.498
<i>FAN</i>	1522	0.939	0.028	33.426	0	0.601	0.600
<i>GLD</i>	1522	0.126	0.027	4.614	0	0.027	0.026

The four green ETFs have significant betas that are large, positive, and significantly large relative to the ACWI (between 0.94 and 1.41 of FAN and TAN respectively). They are used like high-beta industry funds that exaggerate the international equity flows.

Based on the definition of hedge ($\beta \leq 0$), none of the green ETFs can be regarded as a hedge against the risk of global equity market.

GLD has a significantly smaller beta (≈ 0.13); nevertheless, it is positive and statistically significant, which shows that gold is defensive, yet not entirely independent of world equity during this time.

5.3.2 Safe-haven regressions

Safe-haven properties are tested by allowing the beta to change during crisis periods.

The model is:

$$r_{i,t}^e = \alpha_i + \beta_i ACWI_{ext} + \gamma_i (D_t^{crisis} \times ACWI_{ext}) + \varepsilon_{i,t}. \quad (9)$$

where $D_t^{crisis} = 1$ when ACWI's daily return is in the worst 5% of the sample and 0 otherwise. The normal beta is β_i , and the crisis beta is $\beta_i + \gamma_i$. An asset is a safe haven if this crisis beta is zero or negative (Baur & McDermott, 2010).

Table 5 Safe-haven regressions vs ACWI (daily excess returns)

Asset	N	Beta_norm	Gamma_crisis	Beta_crisis	p_beta	p_gamma	R ²	Adj. R ²
ICLN	1522	1.1813	-0.077134	1.1041	0.0000	0.3884	0.5146	0.5140
TAN	1522	1.4928	-0.204814	1.2879	0.0000	0.1717	0.4028	0.4020
CNRG	1522	1.3586	-0.149917	1.2087	0.0000	0.0673	0.5000	0.4994
FAN	1522	0.9569	-0.045015	0.9119	0.0000	0.5045	0.6011	0.6005
GLD	1522	0.1369	-0.026263	0.1107	0.0029	0.7282	0.0273	0.0261

For all assets, the crisis adjustment γ_i is negative but statistically insignificant ($p_gamma > 0.05$). As a result, the crisis betas ($\beta_i + \gamma_i$) remain clearly positive for all green ETFs (between about 0.91 and 1.29) and for GLD (≈ 0.11).

It implies that all the green ETFs do not break the link with the global equity market even in times of steep decline. They thus are not safe-haven behaving in the context of Baur and McDermott (2010). The gold is more defensive than the green ETFs, yet fails to qualify for the rigid safe-haven criterion because its crisis beta is positive.

Overall, the hedge and safe-haven tests demonstrate that the green energy ETFs are pro-cyclical securities, but not equity market risk hedge or safe haven securities.

5.4 Climate Policy Uncertainty and Green ETF Returns

The final step is to test whether **climate policy uncertainty** has an independent effect on green ETF returns after controlling global equity movements. For each asset, the following regression is estimated:

$$r_{i,t}^e = \alpha_i + \beta_i ACWI_{ext} + \delta_i CCPU_t^* + \varepsilon_{i,t}, \quad (10)$$

where $CCPU_t^*$ is the standardised China Climate Policy Uncertainty (CCPU) index.

Table 6 Climate policy uncertainty regressions (daily excess returns)

<i>Asset</i>	<i>N</i>	<i>Beta_ACWI</i>	<i>Delta_CPU</i>	<i>p_beta</i>	<i>p_delta</i>	<i>R²</i>	<i>Adj. R²</i>
ICLN	1522	1.15076	-0.000159	0.00000	0.67780	0.51414	0.51351
TAN	1522	1.41164	-0.000320	0.00000	0.59160	0.40104	0.40025
CNRG	1522	1.29894	0.000022	0.00000	0.95700	0.49855	0.49789
FAN	1522	0.93924	-0.000228	0.00000	0.41490	0.60098	0.60045
GLD	1522	0.12676	-0.000272	0.00000	0.26140	0.02791	0.02663

The ACWI betas are also large and very significant on all assets, which confirms the fact that global equity risk is the most significant risk of green ETF returns.

The CCPU coefficients (δ_i) are very small and insignificant statistically to all green ETFs as well as GLD ($p_{delta} \gg 0.10$).

It means that the statistical significance of daily climate policy uncertainty in China on the daily excess returns of green energy ETFs is statistically insignificant when global market movements are considered.

Green ETFs at the daily frequency act like normal high-beta funds of the equity sector and not a fund that is strongly responsive to short-term climate policy news.

5.5 Summary of Empirical Findings

Based on the new empirical findings, the key findings of this chapter are:

1. Green energy ETFs are less stable compared to the world equity market, and exhibit negative skew and fat tails. They have found a balance in their risk-adjusted performance, with CNRG and TAN appearing relatively favorable and ICLN and FAN being comparatively less strong in their Sharpe ratios.
2. Correlations indicate that the green ETFs are well incorporated in the global and emerging equity markets and exhibit high levels of correlations. They offer thematic clean-energy exposure, but with only a little diversification.
3. The hedge and safe-haven regression models indicate that at normal and crisis times, green ETFs experience large, positive beta with respect to ACWI. This sample does not show them as hedges or safe havens against global equity risk.
4. The climate policy uncertainty, as being measured by the China CCPU index, does not have significant influences on daily excess returns when global equity risk is controlled.

Altogether, it is possible to conclude that the empirical data indicates that green energy ETFs are high-beta and pro-cyclical equity instruments. They play a crucial role as a source of funding the clean-energy change, yet they are not as effective as they should be in offering solid cover against financial risks associated with climate conditions.

6 CONCLUSION

In this thesis, the author discussed whether global clean-energy exchange-traded (ETFs) can assist investors in managing financial risk associated with climate. This empirical analysis utilized 2018-2024 daily data (1,522 trading days) of four major clean-energy ETFs (ICLN, TAN, CNRG, FAN), global and emerging equity indices (ACWI, EEM, BKF) and gold (GLD) with the returns in excess returns over the 3-month 2018 U.S. T-bill (DTB3). The China Climate Policy Uncertainty (CCPU) index was used as a proxy of climate policy risk (Ma et al., 2023).

Two basic yet effective tests were the subject of the research:

- regression analysis hedged and safe-havens on global equity (Baur and Lucey, 2010; Baur and McDermott, 2010), and
- Augmented market models with CPU to determine the pricing of the daily climate policy uncertainty in the returns of green ETFs (Hong et al., 2020; Gavriilidis, 2021).

6.1 Main empirical Findings

- Green ETFs act as risky equity exposures: Descriptive statistics indicate that clean-energy ETFs are less stable and have a larger negative extreme returns than ACWI. The performance of ACWI and GLD are better than the performance of ICLN and TAN in terms of risk-adjusted performance in Sharpe ratio, whereas CNRG and FAN are moderate and not dominating global equities. This aligns with the general findings that most of the green stocks continue to load heavily on conventional market risk factors (Pastor et al., 2021).
- The correlations with the equity markets are quite high: The four green ETFs are most likely to be correlated with a value above 0.85, and the correlations between them and ACWI, EEM and BKF are in the range between 0.63 and 0.86. It implies that clean-energy ETFs do not enjoy the ability to diversify but act as one high-beta sector. Gold, on the other hand, is not correlated with other equity assets, and it continues to play

its diversification role as it has been reported by the literature on safe haven (Baur and Lucey, 2010).

- No hedge, no safe-haven role: Market-model regressions indicate that the betas of green ETFs against ACWI are large and positive (and in many cases greater than one). They cannot be referred as hedges (which have a zero or negative beta) according to the definition of Baur and Lucey (2010). When a crisis dummy is included of the worst 5% of global equity days, crisis betas are also evidently positive and not substantially less than normal betas, thus green ETFs are not safe havens. This is reminiscent of more recent findings that establish only tame or regime-sensitive safe-haven characteristics on green assets (Cepni et al., 2022; Reboredo, 2018).
- Uncertainty in climate policy is not reflected in ICLN returns: In both the CPU-augmented regressions, the ACWI beta is the leading contributor to ICLN, the coefficient of the standardised CCPU index is very small and insignificant. Daily variations in China climate policy uncertainty are not related to ICLN excess returns, even after global equity risk has been taken into account. It coincides with the literature on climate-finance that observes better pricing of climate risks at low frequencies and longer-duration instruments like bonds (Hong et al., 2020; Dutta et al., 2023; Reboredo, 2018).

In general, the data indicates that clean-energy ETFs, in this sample, are the pro-cyclical, high-beta equity funds, as opposed to natural hedges or safe haven against the climate-related financial risk.

6.2 Implications, limitations, and future work

To investors, the key implication is that clean-energy ETFs can be appealing in thematic or sustainability reasons, although it is not likely to decrease the overall portfolio risk or insure against equity market crashes and climate-policy shocks. They resemble more of a concentrated growth/sector exposures, as it would be in the broader ESG and sustainable investing literature (Edmans and Kacperczyk, 2022; Pastor et al., 2021).

To policymakers and regulators, these findings indicate that merely increasing green equity markets cannot help in resilience to climate risk in the financial system. More tools, including green bonds, blended-finance models, climate-aligned disclosure and stress testing, probably should be introduced to align finance with climate objectives (Hong et al., 2020; Dutta et al., 2023; Rasoulinezhad and Taghizadeh-Hesary, 2022).

Its time scope, i.e., between 2018 and 2024, the number of global clean-energy ETFs under consideration (four), and the use of the country-specific CPU index are the limitations of the study. Future studies might further focus that analysis on longer samples, more regions, green bonds, and time-varying or regime-switching models to have a better understanding of the way climate risk and technological innovation are priced in various kinds of sustainable assets (Reboredo, 2018; Dutta et al., 2023).

These shortcomings notwithstanding, the thesis sends one straightforward message: green energy ETFs are valuable tools to fund the energy transition, yet they are at the same time not climate-risk hedges but high-beta equity portfolios. This duality should be realised to come up with portfolios and policies that are financially resilient and in line with long-term climate targets.

References

- Albanese, M., Caporale, G. M., Colella, I., & Spagnolo, N. (2024). The effects of physical and transition climate risk on stock markets: Some multi-country evidence. *International Economics*, 100571. <https://doi.org/10.1016/j.inteco.2024.100571>
- Azad, S., Hayat, A., & Ahmed, A. (2023). Does the energy sector serve as a hedge and safe haven? *Annals of Operations Research*, 339(1–2), 369–395. <https://doi.org/10.1007/s10479-023-05707-6>
- Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7(4), 283–288. <https://doi.org/10.1038/nclimate3255>
- Baur, D. G., & Lucey, B. M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financial Review*, 45(2), 217–229. <https://doi.org/10.1111/j.1540-6288.2010.00244.x>
- Baur, D. G., & McDermott, T. K. (2010). Is gold a safe haven? International evidence. *Journal of Banking & Finance*, 34(8), 1886–1898. <https://doi.org/10.1016/j.jbankfin.2009.12.008>
- Bel Hadj Miled, K. (2025). Nexus between fintech, green finance, natural resources, economic growth and environmental sustainability: Evidence from BRICS countries. *Future Business Journal*, 11(1), 9. <https://doi.org/10.1186/s43093-025-00469-y>
- Benkraiem, R., Dimic, N., Piljak, V., Swinkels, L., & Vulcanovic, M. (2025). Media-based climate risks and the international corporate bond market. *Journal of International Money and Finance*, 151, 103260. <https://doi.org/10.1016/j.jimonfin.2024.103260>

- Bhandary, R. R., Gallagher, K. S., & Zhang, F. (2021). Climate finance policy in practice: A review of the evidence. *Climate Policy*, 21(4), 529–545. <https://doi.org/10.1080/14693062.2020.1871313>
- BloombergNEF. (2025, November 3). A decade after the Paris Agreement, clean energy is making strides in emerging markets but investment gaps persist, BloombergNEF's Climatescope finds. BloombergNEF. <https://about.bnef.com/insights/clean-energy/a-decade-after-the-paris-agreement-clean-energy-is-making-strides-in-emerging-markets-but-investment-gaps-persist-bloombergnefs-climatescope-finds/>
- Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31(3), 307–327. [https://doi.org/10.1016/0304-4076\(86\)90063-1](https://doi.org/10.1016/0304-4076(86)90063-1)
- Bouri, E., Rognone, L., Sokhanvar, A., & Wang, Z. (2023). From climate risk to the returns and volatility of energy assets and green bonds: A predictability analysis under various conditions. *Technological Forecasting and Social Change*, 194, 122682. <https://doi.org/10.1016/j.techfore.2023.122682>
- Broadstock, D. C., & Cheng, L. T. W. (2019). Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. *Finance Research Letters*, 29, 17–22. <https://doi.org/10.1016/j.frl.2019.02.006>
- Bua, G., Kapp, D., Ramella, F., & Rognone, L. (2024). Transition versus physical climate risk pricing in European financial markets: A text-based approach. *European Journal of Finance*, 30(17), 2076–2110. <https://doi.org/10.1080/1351847X.2024.2355103>
- Cavus, M. (2025). Advancing power systems with renewable energy and intelligent technologies: A comprehensive review on grid transformation and integration. *Electronics*, 14(6), 1159. <https://doi.org/10.3390/electronics14061159>

- Cepni, O., Demirer, R., & Rognone, L. (2022). Hedging climate risks with green assets. *Economics Letters*, 212, 110312. <https://doi.org/10.1016/j.econlet.2022.110312>
- Clark, G. L., Feiner, A., & Viehs, M. (2015). From the stockholder to the stakeholder: How sustainability can drive financial outperformance. Arabesque Partners & University of Oxford. [https://arabesque.com/research/From the stockholder to the stakeholder w eb.pdf](https://arabesque.com/research/From%20the%20stockholder%20to%20the%20stakeholder%20w%20eb.pdf)
- Cont, R. (2001). Empirical properties of asset returns: Stylized facts and statistical issues. *Quantitative Finance*, 1(2), 223–236. <https://doi.org/10.1080/713665670>
- D’Orazio, P. (2023). A global database for climate-related financial policies. *BMC Research Notes*, 16(1), 137. <https://doi.org/10.1186/s13104-023-06418-8>
- Dutta, A., Bouri, E., Rothovius, T., & Uddin, G. S. (2023). Climate risk and green investments: New evidence. *Energy*, 265, 126376. <https://doi.org/10.1016/j.energy.2022.126376>
- Edmans, A., & Kacperczyk, M. (2022). Sustainable finance. *Review of Finance*, 26(6), 1291–1322. <https://doi.org/10.1093/rof/rfac069>
- Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environmental Quality Management*, 8(1), 37–51. <https://doi.org/10.1002/tqem.3310080106>
- Elton, E. J., & Gruber, M. J. (1997). Modern portfolio theory, 1950 to date. *Journal of Banking & Finance*, 21(11–12), 1743–1759. [https://doi.org/10.1016/S0378-4266\(97\)00048-4](https://doi.org/10.1016/S0378-4266(97)00048-4)
- Engle, R. F. (1982). Autoregressive conditional heteroskedasticity with estimates of the variance of United Kingdom inflation. *Econometrica*, 50(4), 987–1007. <https://doi.org/10.2307/1912773>

- European Commission. (2019). The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
- European Commission. (2023). Overview of sustainable finance. https://finance.ec.europa.eu/sustainable-finance/overview-sustainable-finance_en
- Fama, E. F. (1970). Efficient capital markets: A review of theory and empirical work. *Journal of Finance*, 25(2), 383–417. <https://doi.org/10.1111/j.1540-6261.1970.tb00518.x>
- Fareed, F., Harutyunyan, A., Hurree-Gobin, P., & Kutlukaya, M. (2024). Going green in finance: Bridging data gaps for enhanced financial risk and opportunities assessment. In IFC workshop on “Addressing climate change data needs: The global debate and central banks’ contribution”. https://www.bis.org/ifc/publ/ifcb63_03.pdf
- Freeman, R. E. (2022). My own book review: Strategic management: A stakeholder approach. *Management*, 25(1), 67–69. <https://doi.org/10.37725/mgmt.v25.8519>
- Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment*, 5(4), 210–233. <https://doi.org/10.1080/20430795.2015.1118917>
- Gao, L., Guo, K., & Wei, X. (2023). Dynamic relationship between green bonds and major financial asset markets from the perspective of climate change. *Frontiers in Environmental Science*, 10, 1109796. <https://doi.org/10.3389/fenvs.2022.1109796>
- Gavriilidis, K. (2021). Measuring climate policy uncertainty. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.3847388>

- Green Finance Platform. (2016). Explore green & sustainable finance. <https://www.greenfinanceplatform.org/page/explore-green-finance>
- Guo, N., Jia, S., & Liu, Y. (2025). Climate policy uncertainty and its impact on sovereign borrowing costs. *Environment, Development and Sustainability*. <https://doi.org/10.1007/s10668-025-06261-w>
- Henriques, I., & Sadorsky, P. (2008). Oil prices and the stock prices of alternative energy companies. *Energy Economics*, 30(3), 998–1010. <https://doi.org/10.1016/j.eneco.2007.11.001>
- Hong, H., Karolyi, G. A., & Scheinkman, J. A. (2020). Climate finance. *Review of Financial Studies*, 33(3), 1011–1023. <https://doi.org/10.1093/rfs/hhz146>
- International Energy Agency. (2022, October 27). World energy outlook 2022 shows the global energy crisis can be a historic turning point towards a cleaner and more secure future. IEA. <https://www.iea.org/news/world-energy-outlook-2022-shows-the-global-energy-crisis-can-be-a-historic-turning-point-towards-a-cleaner-and-more-secure-future>
- International Energy Agency. (2023). World energy investment 2023. <https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf>
- International Energy Agency. (2025). Energy technology patents data explorer [Data tool]. <https://www.iea.org/data-and-statistics/data-tools/energy-technology-patents-data-explorer>
- International Monetary Fund. (2022). Approaches to climate risk analysis in FSAPs (IMF Staff Climate Note No. 2022/001). <https://www.imf.org/en/Publications/staff-climate-notes/Issues/2022/07/12/Approaches-to-Climate-Risk-Analysis-in-FSAPs-519515>

- International Monetary Fund. (2022). Global financial stability report, October 2022: Navigating the high-inflation environment. <https://www.imf.org/en/Publications/GFSR/Issues/2022/10/11/global-financial-stability-report-october-2022>
- Khamis, M., & Aassouli, D. (2023). The eligibility of green bonds as safe haven assets: A systematic review. *Sustainability*, 15(8), 6841. <https://doi.org/10.3390/su15086841>
- Kouwenberg, R., & Zheng, C. (2023). A review of the global climate finance literature. *Sustainability*, 15(2), 1255. <https://doi.org/10.3390/su15021255>
- Kyei, S. K., Boateng, H. K., & Frimpong, A. J. (2025). Renewable energy innovations: Fulfilling SDG targets. *Clean Energy*, 9(2), 190–203. <https://doi.org/10.1093/ce/zkae109>
- Lintner, J. (1965). The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets. *Review of Economics and Statistics*, 47(1), 13–37. <https://doi.org/10.2307/1924119>
- Ma, Y.-R., Liu, Z, Ma, D., Zhai, P., Guo, K., Zhang, D., & Ji, Q. (2023). A news-based climate policy uncertainty index for China. *Scientific Data*, 10(1), 881. <https://doi.org/10.1038/s41597-023-02817-5>
- MacKinlay, A. C. (1997). Event studies in economics and finance. *Journal of Economic Literature*, 35(1), 13–39. <http://www.jstor.org/stable/2729691>
- Markowitz, H. (1952). Portfolio selection. *Journal of Finance*, 7(1), 77–91. <https://doi.org/10.2307/2975974>
- Network for Greening the Financial System. (2021). NGFS climate scenarios for central banks and supervisors. <https://www.ngfs.net/en>

- Newey, W. K., & West, K. D. (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3), 703–708. <https://doi.org/10.2307/1913610>
- Okeke, I., Bakare, A., & Godwin, N. (2024). Integrating policy incentives and risk management for effective green finance in emerging markets. *International Journal of Frontiers in Science and Technology Research*, 7(1), 76–88. <https://doi.org/10.53294/ijfstr.2024.7.1.0050>
- Pástor, L., Stambaugh, R. F., & Taylor, L. A. (2021). Sustainable investing in equilibrium. *Journal of Financial Economics*, 142(2), 550–571. <https://doi.org/10.1016/j.jfineco.2020.12.011>
- Rabbani, M. R., Kiran, M., & Shaikh, Z. H. (2025). Financing the future: Insights into sustainable energy investments through scientific mapping and meta-analysis. *Discover Sustainability*, 6(1), 1–18. <https://doi.org/10.1007/s43621-024-00788-0>
- Rasoulinezhad, E., & Taghizadeh-Hesary, F. (2022). Role of green finance in improving energy efficiency and renewable energy development. *Energy Efficiency*, 15(2), 16. <https://doi.org/10.1007/s12053-022-10021-4>
- Reboredo, J. C. (2014). Is there dependence and systemic risk between oil and renewable energy stock prices? *Energy Economics*, 48, 32–45. <https://doi.org/10.1016/j.eneco.2014.12.009>
- Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Economics*, 74, 38–50. <https://doi.org/10.1016/j.eneco.2018.05.030>
- Ryan-Collins, J. (2019). Climate-related financial policy in a world of radical uncertainty: Towards a precautionary approach (Working Paper No. IIPP WP 2019-13). University College London. https://discovery.ucl.ac.uk/id/eprint/10195939/1/Ryan-Collins_iipp-wp-2019-13-climate-related-financial-policy-in-a-world-of-radical-undertainty-web.pdf

- Sharpe, W. F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk. *Journal of Finance*, 19(3), 425–442. <https://doi.org/10.2307/2977928>
- Sharpe, W. F. (1966). Mutual fund performance. *Journal of Business*, 39(1), 119–138. <https://doi.org/10.1086/294846>
- United Nations Conference on Trade and Development. (2023). BRICS investment report. https://unctad.org/system/files/official-document/diae2023d1_en.pdf
- United Nations Conference on Trade and Development. (2023). World investment report 2023: Investing in sustainable energy for all. <https://unctad.org/publication/world-investment-report-2023>
- United Nations Environment Programme Finance Initiative. (2023). Principles for responsible banking. <https://www.unepfi.org/banking/bankingprinciples/>
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data* (2nd ed.). MIT Press.
- World Bank. (2015). World development indicators [Data set]. <https://databank.worldbank.org/source/world-development-indicators>
- World Bank. (2024). Finance & prosperity 2024. <https://www.worldbank.org/en/publication/finance-and-prosperity-2024>
- Yang, J., Mirza, H., Kaium, M. A., & Salahodjaev, R. (2023). Financial indicators' performance and green financing projects: A comparative study from PSX and NYSX. *Sustainability*, 15(6), 5132. <https://doi.org/10.3390/su15065132>
- Zhang, S. Y. (2022). Are investors sensitive to climate-related transition and physical risks? Evidence from global stock markets. *Research in International Business and Finance*, 62, 101710. <https://doi.org/10.1016/j.ribaf.2022.101710>