LIBERA UNIVERSITÀ INTERNAZIONALE DEGLI STUDI SOCIALI

Department of Economics and Finance
Chair of Theory of Finance

Going Green:
Analysis of a Sustainable Portfolio

SUPERVISOR
Nicola Borri

CANDIDATE
Eleonora Mascelluti
676751

CO-SUPERVISOR
Federico Nucera

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Abstract

Climate change is a fundamental concern that poses serious threats to the ecosystems in which we live and, in turn, to our present and future well being. Nowadays, the importance achieved by climate change is having repercussions on many aspects, including the financial one, which is the main subject of the study.

The thesis investigates the extent to which green bonds, a recently developed tool whose proceeds are used exclusively to finance environmental projects, will be able to meet investors' increased appetite for green projects. The study aims at assessing whether green bonds are already responsible for delivering some diversification benefits to portfolios, and whether these benefits differ due to the type of investor considered. The distinction among the types owes to their preferences, accordingly it is possible to distinguish between investors characterized by standard mean-variance preferences and those, which in the study are referred to as *green* investors, who retrieve higher utility values from green financial products.

The results from the two mean variance analyses suggest that green bonds, proxied in the thesis by selected green bond indices, do not deliver substantial benefits to investors in case the latter would require high amount of expected returns. Nonetheless, there are some positive figures which emerge and that endorse the importance gained by green bonds in the latest years, in particular the emergence of green bonds as investment choice for portfolios demanding lower expected returns, even in the case of conventional mean-variance preferences' investors. Finally, outcomes from the constrained optimization problem, which in the thesis is applied to the case of green investors, seem to suggest that a slightly higher risk must be undertaken by investors willing to hold green securities, although the increase is negligible especially in the case of a moderate green investor.

Despite the small benefits brought by the introduction of green bond indices considered in this study, the introduction of more and more green features into portfolios seems to be plausible and in line with the current trend of government and climate-policymakers to push investments towards a greener financial scenario.

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Introduction

The continuous growth of the world population, the scarcity of resources and the environmental pressures are major determinants of the transition phase towards a greener and sustainable planet we are currently experiencing. Climate change is a fundamental concern that poses serious threats to the ecosystems in which we live and, in turn, to our present and future well being. In the past decade, governments all over the world have committed to tackle climate change issues by reinvigorating national economies through sustainable economical, social and environmental growth sources. Governments have recognized the need to consider climate change policies, particularly due to the effects they have on sustainable development and poverty alleviation. In the Paris Agreement adopted in December 2015 by the 21st Conference of the Parties to the United Nations Framework Convention on Climate (COP21), countries have agreed to strengthen the global response to the threats of climate change by keeping a global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degree Celsius.[1]

In order to move towards low-carbon economies and to achieve poverty reduction and sustainable livelihoods, investments into green employment, biodiversity conservation, renewable energies, sustainable water management and waste management need to be implemented on a national basis. Nonetheless, advanced economies have recently suffered from a deficit of public infrastructure investments, whilst developing economies have lacked the possibility of providing access to modern services to their growing population. Accordingly, the ability to gather the right type of investments for the infrastructure sector is fundamental for the transition path. Climate policymakers have thus the responsibility of creating incentives to promote green growth and to encourage investments in sustainable projects from the private sector.

The increasingly importance of sustainable and environmental investments had its repercussions on financial markets as well; the latter have become paramount to solve the climate challenge, by meeting the growing demand for low-carbon projects around the world. As a matter of fact, new financial tools aimed at directing capital to green projects have been developed, and are becoming widespread as the benefits they deliver have been progressively recognized. Debt securities have been used to finance low carbon and climate resilient infrastructures for a while now, however it was only in 2007 that a market for bonds specifically designated as “green” has emerged. The main difference between green bonds and conventional ones concerns the use of the earmarked proceeds; indeed,

[1] United Nations, Framework Convention on Climate Change

green bonds are debt instruments issued with a commitment to finance exclusively eligible green projects and infrastructures.

Green bonds appear to be a suitable candidate instrument, consistent with climate change mandates, to promote sustainable growth. Moreover, as the majority of developing countries is committing to maintain a fast pace of growth by investing in sustainable and renewable resources, green bonds have the potential to enable this growth by creating a bridge between the financial and the environmental scene.

To provide empirical results which could highlight the great potential of green bonds, two mean variance analyses have been conducted with the intent of assessing potential benefits brought by the inclusion of green bonds in investors' portfolios. The analyses are implemented by considering an unconstrained optimization problem first, and a constrained one afterwards. The reason for the two types of optimization is coherent with the idea that ideally *green* investors would retrieve higher utility values when holding portfolio comprising green securities. The aim is to understand whether these green investments are already capable of offering attractive returns to investors, or whether we are still experiencing a transition phase that sees the emergence of green securities but whose potential has not yet been realized. Nevertheless, there is no doubt that the newly developed green bond market and the actions undertaken by climate policymakers, governments and states are pointing to the same direction: a world where sustainability is among the major determinants of growth and well-being.

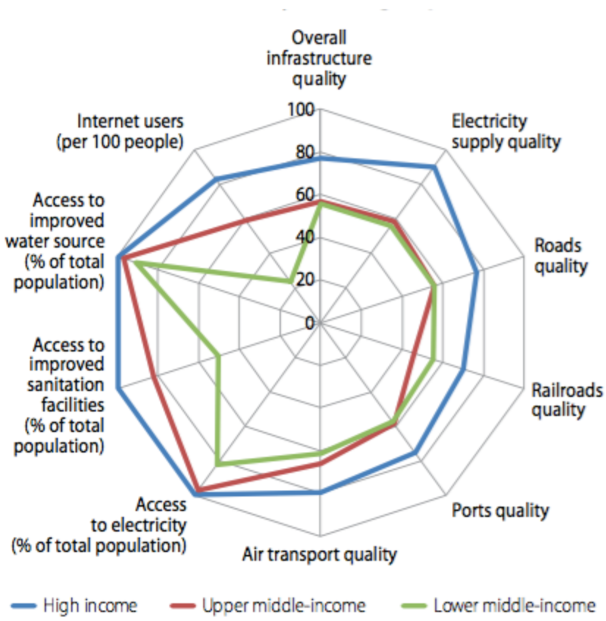
The paper is organized as follows. Chapter 1 describes the green bond market by providing detailed insights about the intrinsic features of green bonds, the principles governing the issuances and the advantages and disadvantages incurred by both investors and issuers. Chapter 2 proposes a literature review for traditional portfolio theory and then explores the studies which have dealt with green investments so far, by tracing a distinction between equity and bonds. Chapter 3 entails the consideration of the Theoretical Framework on which the empirical analysis is based. First, it presents a subchapter focused on the utility functions considered in the study. Namely, it first analyses the features of mean-variance preferences, and then explores the way in which a utility function build on green preferences would look like. Finally, it defines the model implied for the empirical computations of the thesis. Chapter 4 encompasses the empirical analysis; the first part of the chapter is devoted to the identification of some potential benefits arising from the consideration of green bonds in the standard optimal portfolio decision making process, whilst the second part repeats the analysis by considering how the optimal portfolio choice would change based on the type of investor considered. The paper ends with some comments and conclusions.

1. The Green Bond Market

1.1. The Background

The quality of infrastructure is a vital component for a country's development, as it increases the chances to maintain a sustainable economic growth. Infrastructure investments differ significantly across countries, with the implication of asymmetric growth rates prompted by ease of access to basic services. Enormous level of infrastructure investments is needed nowadays to support economic growth and to cope with the necessity of providing basic needs to the growing population, especially in emerging countries where urbanization is advancing. According to a newly published OECD report, approximately USD 95 trillion of infrastructure investments are expected in the next 15 years, of which transport and energy represent 43% (OECD, 2017).

Figure 1. **Quality of Infrastructure status and access to basic services in G20 countries, by income groups.**



Source: OECD 2017, Investing in Climate, Investing in Growth

The vast majority of contemporaneous infrastructures was designed specifically for a world able to provide abundant and cheap fossil fuels. Nonetheless, the emerging environmental threats have raised awareness about the necessity to invest in low-carbon climate resilient infrastructures to ensure a long lasting economic growth. According to International Energy Agency, the incremental costs of low-carbon infrastructure investments is relatively modest; it would only entail a 4.5% increment relative to the normal business, but it would provide with longer term benefits that will considerably outperform the costs.

The failure to invest today in the right type of infrastructure implies serious environmental damages, as well as financial instability preventing economies from growing further. Accordingly, sustainable infrastructure investments would allow to boost economic growth and development in the short term, and provide a solution to sizable problems such as pollution, congestion and access to energy.

Governmental structural reforms in the field of climate policies that aim at attracting interests-aligned investments are crucial for guiding countries in the low-carbon climate resilient process. Certainly, country's specific characteristics influence the way and the extent to which these reforms are implemented on a national basis. On the one hand, the public sector has a critical role in ensuring that infrastructure investments are supporting economic and climate-related issues. On the other, it is responsible for shaping an environment that favours the speed up of private investments into environmentally sustainable projects. Therefore, governments need to exploit the available public capital to mobilise a much greater investment of private funds, necessary to promote a re-allocation of invested capital into low-carbon and climate resilient options.

"Coherent climate policy and a well-aligned investment framework are essential to steer the investment flows needed to pursue a low-emission, resilient pathways, but in themselves they are not enough." (OECD, 2017)

Private financing of infrastructure has gained major importance, particularly for the renewable energies' sector which, in the last decade, has been the one attracting a massive flow of investments. Nevertheless, the substantial risk perceived when financing infrastructures has hampered the flow of private funds into infrastructure projects, especially in emerging countries. Moreover, political, regulatory, macroeconomic, business risks and, ultimately, climate change risk further hinder private investments. Several risk mitigations and financial approaches have been developed to cope with the above mentioned issues; financial tools range from guarantees and credit enhancement to currency hedging, whilst new instruments such as green bonds grant a reliable long-term funding basis for infrastructure projects.

The main concern remains the willingness to shift actual investments from emission intensive towards LCR infrastructures, and to discover the way to properly finance these projects.
Furthermore, an enabling policy context is required for banks and corporate to keep maintaining a significant role as providers of direct financing to LCR[2], although bond markets are materializing on their side to support and further enhance financial means. Indeed, bonds have the potential to either

[2] Low-carbon, Climate resilient Infrastructure

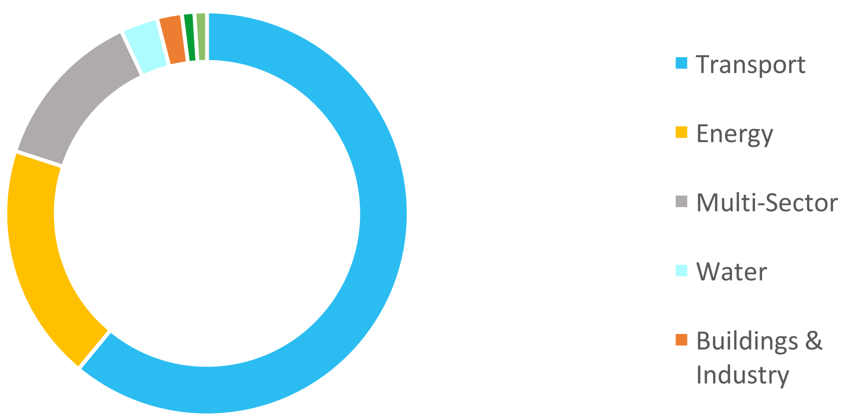
raise capital directly for LCR projects or refinancing enduring short-term loans at a lower cost. As a matter of fact, a large proportion of LCR infrastructures is currently financed by debt, as this form of financing suits perfectly LCR characteristics of high-upfront capital costs and long term maturity. However, it is only since 2007 that a market for bonds specifically self-labelled and designated as "green" has emerged.

1.2. What is a Green Bond?

Green bonds are fixed income financial instruments issued to raise capital with the purpose of backing climate or environmental projects. The specific use of the proceeds is what distinguishes a green bond from a regular one; namely the label "green" identifies a commitment to use the proceeds of the green bonds, the principal, in a transparent manner and exclusively for the financing of eligible green projects.

A distinction worth noting is that between green and unlabelled climate related bonds, the latter being debt securities with climate related underlying assets but whose proceeds are not specifically earmarked for climate or environmental projects. A major difference between the two types of bonds consists of the average tenor; labelled green bonds have tenors ranging from 5 to 10 years whilst unlabelled green bonds' tenor is usually set at 10 or more years. The difference originates from the large presence of large state-backed entities responsible for financing the majority of sustainable transportation projects, whose horizons are evidently longer, in the climate aligned framework (Climate Bonds Initiative, 2016). Despite the broad application of green bonds' proceeds to several green projects, most of the proceeds have still been allocated to LCR infrastructure' investments.

Figure 2. **Outstanding climate-aligned bonds per sectors**



Source: Climate Bonds Initiative: The State of the Market 2017.

Whenever sectors of investments are taken into consideration, the transport sector prevails with 61% of all outstanding bonds, whilst the energy sector accounts for 19% of the outstanding bonds. Among others we find water (3%), buildings and industry (2%), agriculture and forestry (1%) and waste and pollution control (1%). Finally, the remaining 13% consists of bonds simultaneously financing multi-sectors (CBI, 2017).

1.2.1. The pricing of green bonds

Green bonds have been associated to the concept of flat pricing, precisely due to the identical credit profile of a green bond when compared to a standardized bond of the same issuer. Yet, pricing has been the main focus of the ongoing debate between issuers, who would like to be compensated for the extra issuance costs undertaken to face the increasing green demand, and investors who, on the contrary, are not willing to pay a high price if not rationalized by a risk-adjusted return criterion. If green bonds traded at a premium compared to conventional bonds of the same issuers, it would entail that a significant proportion of investors would value the label itself, delivering issuers a considerable incentive to issue green bonds. As a result, green bonds should observe an increase in the issuance's price if a substantial number of investors would be willing to buy them at a premium (Ehlers and Packer, 2017).

According to BNEF, issuers have not been able to exploit any kind of price advantages driven exclusively by the distinct green feature of the bond, as the majority of investors is reluctant to earn slightly lower returns at the primary issuance just because a bond is designated as green (OECD, 2015). On the contrary, a Barclay's report of 2015 has brought to the attention that green bonds trade de facto at a premium, at least on secondary markets. Several hypotheses have been considered to shed light on the difference in valuation, however due to the modern and blurred scenario characterizing the green bond markets, it has not been possible to derive conclusive statements.

1.2.2 Green bonds' typologies

Before analysing pros and cons faced by issuers and investors in the green market, it seems sensible to analyse the different forms a green bond can be categorised into, likewise considering some examples of green bonds by type of issuer.

A corporate green bond, besides the specific use of proceeds, behaves as a standard one enabling recourse to the issuer in case of default on interest payments or principal repayment. A project green bond is one according to which the investor has direct exposure to the risk associated to the projects;

depending on the specific issue it comes with or without recourse to the issuer. Whenever a green bond takes the form of an asset-backed security, it entails that the bond is collateralised by one or more projects. As with standard ABS, it prescribes recourse to the projects' assets, with the only exception of a covered green bond which anyway is subject to the rules applied to a conventional bond (primary recourse to the issuer and secondary recourse, in case of default, to an underlying covered pool of assets). A supranational, sub-sovereign and agency (SSA) bond has characteristics that are similar to those of a corporate bond for what concerns the ear-marked of proceeds, although it is issued by international financial institutions as the World Bank and the European Investment Bank. Municipal green bonds are those issued by a municipal government, region or city to gather financing for the multitude of municipal infrastructure and climate projects in need (Climate Bond Initiative). Finally, a financial sector bond is a sub-type of corporate bond issued by an entity purposely to raise money for loans supporting green activities (OECD, 2015).

The main investors of green bonds are institutional ones, including national development banks, insurance companies, pension funds and others. Nonetheless, private investors are increasingly emerging in Europe, Japan and the Americas. Among institutional investors, the most active ones are pension funds and insurance companies. In much, pension funds are largely interested into investments characterized by lower risk, able to provide them with a steady, inflation-adjusted income stream. Their investment perspective is perfectly matched by green bonds associated to sustainable projects, especially those linked to energy sources and clean technology, requiring a financial vehicle able to face the various investments needed at different stages of maturity and for a heterogeneous number of technologies (Della Croce, Kaminker and Stewart, 2011).

On the issuers' side, the green bond market is characterized by a vast heterogeneity of profiles, ranging from multilateral development banks to municipalities and corporations. The quality of the issuer depicts the credit risk of the bond, thus the above mentioned heterogeneity of issuers contribute to offering of a variety of green bonds associated to different levels of risk (Cochu *et al.,* 2016).

1.3 Certifications and External Reviews

As the green bonds market continues to expand, issuers and investors are more and more concerned about the definitions and processes associated with green bonds. The willingness to bring greater clarity into the picture has boost the research upon standards and criteria applying to green bonds. On the one hand, the lack of precise rules, standards, applicable criteria, missing reporting and impact assessment are all pivotal reasons preventing investors to support green projects and activities. On the other, issuers face accusations of "green-washing" if they fail to allocate the proceeds into the planned projects or if they are unable to prove the proceeds have been invested in activities bringing positive environmental impact. An ultimate concern is that stringent requirements for what qualifies as a green bond could slow or, even worse, constrain the use of green bonds as a source of capital for LCR investments. To deal with those issues, abundant effort has been employed to deliver a comprehensive description and guidelines for what to be identified as a "green" investment (OECD, 2015).

1.3.1. Green Bond Principles

Driven by market and government efforts, a group of banks, following earlier experiences of multilateral development banks in 2014, managed to develop a set of voluntary guidelines designated to support disclosure and transparency in the green bond market, namely the Green Bond Principles (GBP). "The GBP define green bonds as any type of bond instruments where the issuance proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects and which follows the four Green Bond Principles" (OECD, 2015).
The GBP do not provide strict categories according to which a project qualifies as green, although it tries to clarify as much as possible the process undergone by issuers when dealing with the bond's proceeds. The principles guide the issuers into the path of green bonds' issuances requesting to specify (i) the use of proceeds for environmentally sustainable activities, (ii) the process resolving project eligibility, (iii) criteria according to which proceeds can be tracked and verified and (iv) annual reports on the actual use of proceeds. (Ehlers and Packer, 2017).

1.3.2. Climate Bonds Standard

Differently from the GBP, the standards set by the Climate Bonds Initiative provide criteria for assessing the green credentials of bonds or alternative debt instruments. It consists of a strict and defined approach for verifying that selected securities are supporting the path towards a low carbon and climate resilient economy. The Climate Bonds Standard is an environmental standard that, however, still requires financial due diligence: it contributes to facilitate decision-making whenever green features are involved, and highlights how debt capital markets' instruments can be used as feasible climate change solutions (Climate Bonds Initiative).

The Climate Bonds Standards & Certification Scheme can be thought of as a cornerstone for the creation of a clear and solid certification system. Among its features, the most significant ones are undoubtedly the full alignment with the latest version of the GBP, the transparent requirements concerning the effective use of proceeds, and the specific eligibility criteria for green projects and the certification by an independent Climate Bonds Standard Board. On the one hand, investors are facilitated in the process as they can avoid taking subjective decisions or exercise expensive due diligence on green features of certified investments. On the other, certifications help issuers in demonstrating their bonds are in line with the standards for climate resilient solutions and the proceeds' use (Climate Bonds Initiative).

1.3.3. External Reviews

Due to the blurred scenario framing the green bond market, a rather numerous number of verifiers and third party reviewers has emerged, with the aim of assessing the environmental integrity of a process. By the same token, to avoid dealing with wrong projects and to check the bonds' compliance with the originated standards, issuers rely on external reviews and third-party certifications. "As of October 2015, 60% of total green bond issuance to date has officially incorporated a second-party review, and this percentage has remained stable over the past three years" (OECD, 2015). The rationale behind the intense effort undertaken by issuers, investors and governments lies in the hope of achieving a convergence towards worldwide commonly accepted standards, facilitating the matching and the transactions between green issuers and socially responsible investors.

External reviews are conceived to cope with one of the main problem that characterizes CBI standards and green bond indices, that is their binary nature: namely, a bond is either green or not. A differentiated assessment could provide investors with additional information and clarity, by shedding light on the degree of environmental benefits or, for instance, whether the environmental benefits a green bonds entails are likely to persist (Ehlers and Packer, 2017). Among external reviewers the most popular ones are CICERO, Moody's Green Bond Assessments and Standard & Poor's Green Evaluations. The former is a climate research institute based in Oslo whose second opinions are based on different "shades of green" reflecting the bond's ability to fit in a long-term perspective of low carbon resilient economy. However, CICERO's reviews occur at the time of issuance, thus any subsequent change in the green bond's environmental impact is not assessed. Moody's Green Bond Assessments concern the evaluation of the probability that the bonds' proceed will be truly invested to support environmental projects in line with the GBP. Finally, Standard & Poor's, which has introduced these green evaluations just in the recent 2017, provides ratings that include a technical environmental impact assessment component, beyond the governance and transparency components. The rating consists of a score in between zero and 100, that serves to analyse the overall expected lifetime environmental impact, ceteris paribus (Ehlers and Packer, 2017).

1.4 Advantages and Disadvantages of Green Bonds

After having exposed some commonly accepted standards that function as the underlying basis for green bond investments, it is relevant to consider advantages and disadvantages, faced by both issuers and investors, in the green bond market framework.

When considering green bonds' issuers, the benefits associated to the transactions outweigh the costs. Although the capital raised through a green bond issuance does not differ much from the one that could have been raised with a conventional bond, there are some effects that are intrinsic to the green bond nature. The first one concerns the possibility of broadening the investor base to some type of investors which are solely interested in projects dealing with environmental and climate-related issued, namely socially responsible investors and those incorporating environmental, social and governance (ESG) preferences. A diversified investor base has the potential to expand the funding sources, thus releasing issuers from the specificity of the markets in which they operate, and reducing their exposure to bond demand fluctuations. The main disadvantages encountered by issuers are higher up front and ongoing transaction costs originating from the green labelling and several administrative, verification and monitoring costs. Moreover, issuers may be asked to pay some penalties to investors in case they break agreed green clauses, even after having repaid in full the principal. Of course, the latter poses constraints on green bond issuances (OECD, 2015).

When shifting the attention to the investors' side, the straightforward benefit concerns the opportunity to invest in green projects without incurring in any additional risk or cost. Moreover, the additional transparency requirements for what concerns the use of proceeds enables investors to better assess the risks associated to a precise bond. The latter also contributes to provide investors with otherwise unavailable information, as those on spending efficiency, project details and updates, as well as impact performance (Climate Bonds Initiative). Investors' struggles are mostly related to the small size of the market, and thus the small size of the issuances; this prevent many small green projects to be financed due to minimum requirements issuers face. Finally, lack of standard criteria may boost complexities in research and may prescribes some extra level of due diligence which may not be met (OECD, 2015).

To conclude, there are undoubtedly drawbacks, mostly justified by the recent development of the green bond market, which however can be easily tackle and presumably overcome as experience and evidence in the field advance. Nevertheless, the comprehensive number of benefits retrieved by both issuers and investors in the green bonds market far outperform the costs, and are expected to increase as knowledge of the market and its functioning are more exhaustively assessed.

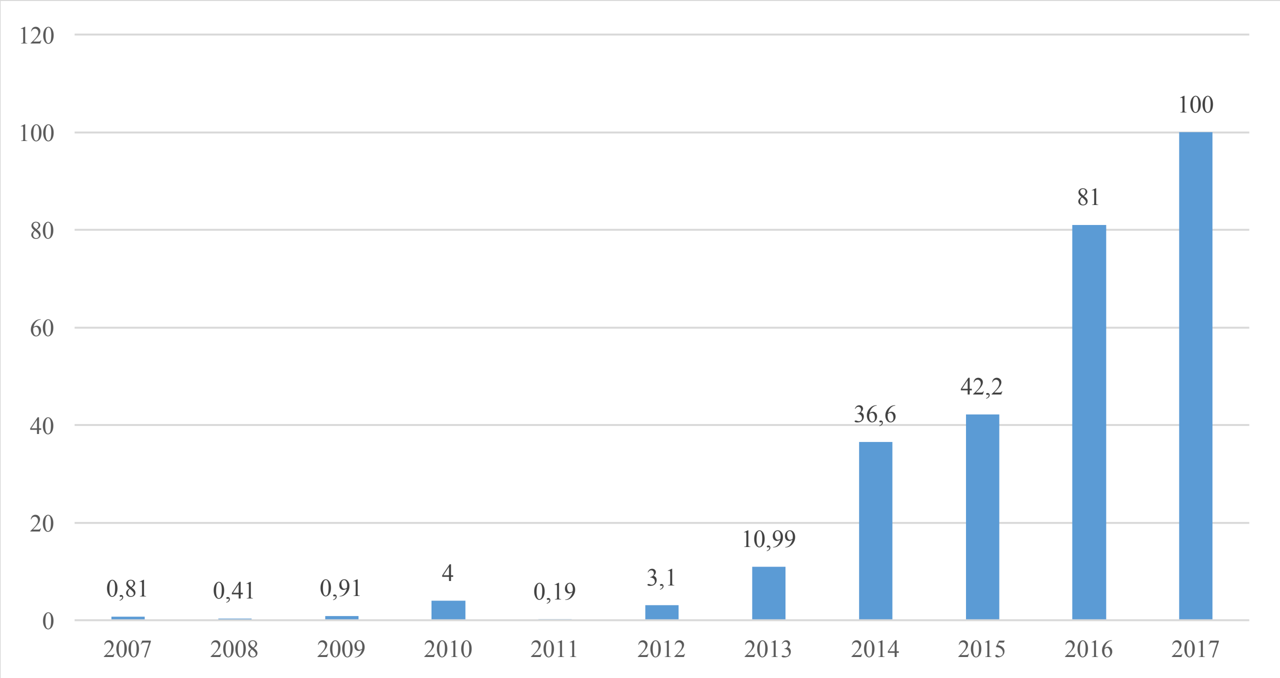
1.5 Evolution of the Green Bond Market

"The labelled green bond market continues to grow year-on-year and currently amounts to over $118bn outstanding". [3]

The first climate-labelled bond was issued by the EIB in 2007, a Climate Awareness Bond (CAB) worth EUR 600 million, with a specific focus on renewable energy and energy efficiency. Just one year later, the World Bank issued the first labelled "green" bond of approximately USD 440 million, to meet the demand of a Scandinavian pension funds concerned with supporting climate related projects. By 2010, the growing awareness of green bonds led Multilateral Development Banks and a number of governments, agencies and municipalities to issue an amount of USD 4 billion worth of green bonds. The major shift occurred in 2013, when the first corporate green bonds were issued in the United States by Bank of America's financial sector bonds. Thereafter, an increasing number of corporations, energy utilities and other agencies joined the market, allowing it to triple in size in a very short period of time. During that same period, municipalities' green bond issuances also emerged, with the first issuance by Ile de France in 2012 (OECD, 2015). The increasing pace was maintained in 2014, when the green bond market reached a value of over USD 37 billion, half of which was issued by public corporation and public entities (The World Bank, 2015). The year 2015 was an important one as well, mostly because many more additional countries connected to the green bond market with their issuances. Among the newcomers, those whose issuance contributed the most to the increase in the overall market's value were Brazil, Mexico, China and India. For instance, they encompass the first Chinese RMB offshore green bond by Agricultural Bank of China, the first India green bond by YES bank and the first Brazilian green bond by food produced BRF (Cochu *et al.,* 2016). Until 2016, a large part of the proceeds was allocated to renewable energy and energy efficiency, however the increased participation of development banks, corporates and municipalities has allowed to broaden their use to other sectors that include water, transport and waste management projects. As a matter of fact, during 2016 the total volume of green bonds issuance doubled with respect to the previous year, reaching an amount of USD 81.4 billion. The green bond market has kept its sustained pace of growth in 2017 and has broken new records, exceeding the $100bn mark. Sovereign issuance of green bonds is what has prompt the growth in 2017, with Poland being the first sovereign green bond issuers as of December 2016. Shortly after, and more precisely in January 2017, France issued the largest green bond to date of EUR 7bn (Climate Bonds Initiative, 2017).

[3] Climate Bonds Initiative, 2016

Figure 3. **Volume of Issuance of Green Bonds – USD bn dollar**



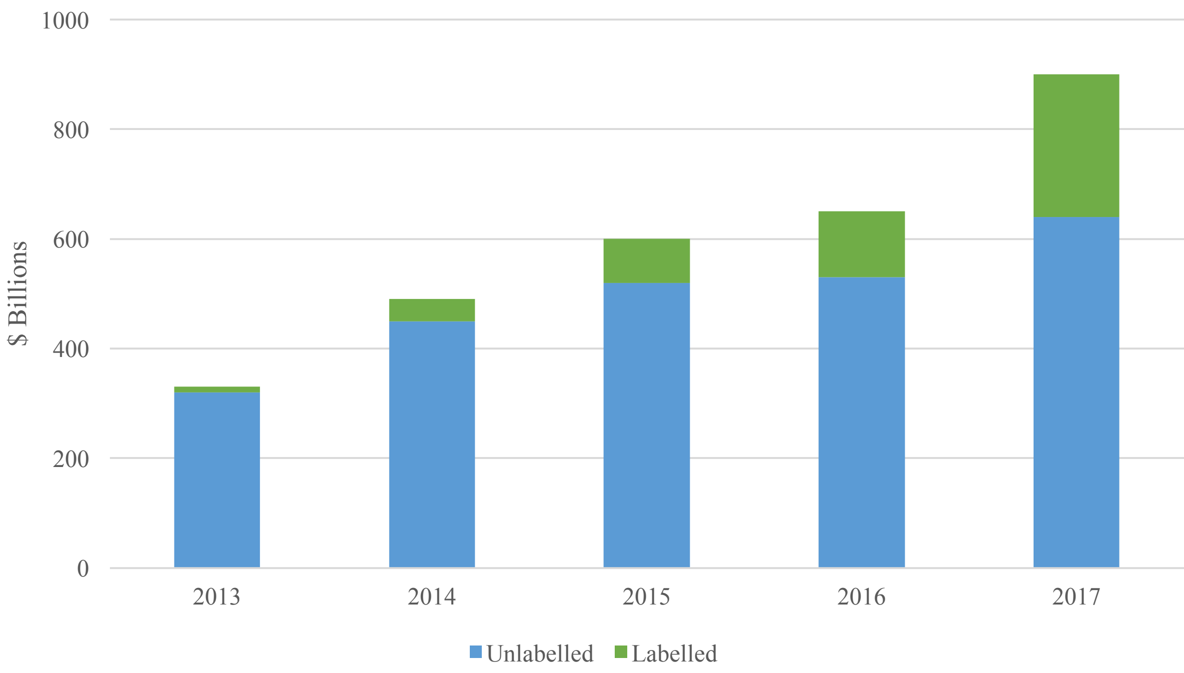
Source: Climate Bonds Initiative[4], SEBI Consultative Paper[5]

The relevant growth that has characterized the green bond market in the latest year, is a major determinant for the consequent increase in size of the climate universe as a whole. As shown in Figure 4 below, labelled green bonds are accountable for the growing share of the climate-aligned bond market. Undoubtedly, the strong demand for green bonds has made oversubscription for these type of securities become a common norm in the green market. Even though it is hard to establish an upper limit for green bonds' demand, the emergence of copious green bond indices and funds has increased and is probably going to lead to a further increase of the green bond market. If on the one hand, demand for green bonds is what has boosted investments, on the other, the fact that green bonds come with the same structure of plain vanilla bonds has made them equally attractive to investors who are not concerns with the green label at all (Climate Bonds Initiative, 2017).

4 https://www.climatebonds.net/

5 http://www.sebi.gov.in/sebi_data/attachdocs/1449143298693.pdf

Figure 4. **Relevance of labelled green bonds in the climate-aligned universe**



Source: Climate Bonds Initiative: State of the Market 2017

1.6 *Adapting Portfolios to Climate Change*

Worldwide investors have largely increased the proportion of investments in green bonds within their existing portfolio, in response to their willingness and interest to support sustainable projects and activities. Indeed, neglecting climate change and its associated risk is not anymore a possibility. This section focuses on climate change's risks that could have an impact on investors' portfolios, thus delivering an idea of why climate change awareness could foster green bonds' investments.

Although the majority of countries in the world is well aware of environmental issues and has been taking actions to deal with them, governments, investors and consumers have been much slower to recognized the threats, mostly due to behavioural biases. Indeed, both risks and opportunities which do not occur in the nearest future are likely to be underestimated, as individuals are not able to identify the significant impacts they could deliver in the longer period. However, as time passes by and as these effects materialize, it becomes essential to face climate change and to deal with its associated risks. In accordance, climate change is assumed to deliver risks and benefits through four channels, namely physical, technological, regulatory and social channels.

For what concerns the former, intense human activity has been responsible for the increase in extreme events such as storms, droughts, wildfires, as well as the rises in temperatures and sea levels over time. Although these physical effects are hard to model and are very heterogeneous across countries, it is already possible to detect, and in some cases estimate, the impacts they will bring. For instance, coastal companies in vulnerable areas will be damaged from the increase in sea level if no precaution to limit a further increase is taken, and this translates as a loss for someone who has invested in the company's shares. A solution to mitigate physical climate-related risks could entail investing in a sustainable oriented index or lowering a portfolio's carbon footprint (Hildebrand and Winshel, 2016).

Technological risk is mainly associated to the concept of "stranded asset", assets that either become unusable or whose usage or extraction costs exceeds their potential revenues. The stranded assets' issue raised awareness among investors and companies who started to worry, fearing a collapse in their holdings, and thus reduced their exposure to fossil fuels-related companies (Butler, 2015).
These worries are become progressively well-founded, given governments' decisions to constrain oil, gas and coal pollution to tackle climate change, and this is something which would be referred to as regulatory risk. Governments' interventions aiming at favouring some industries over others have immediate and often negative repercussions on shareholders' investments, provided they are unable to anticipate them.

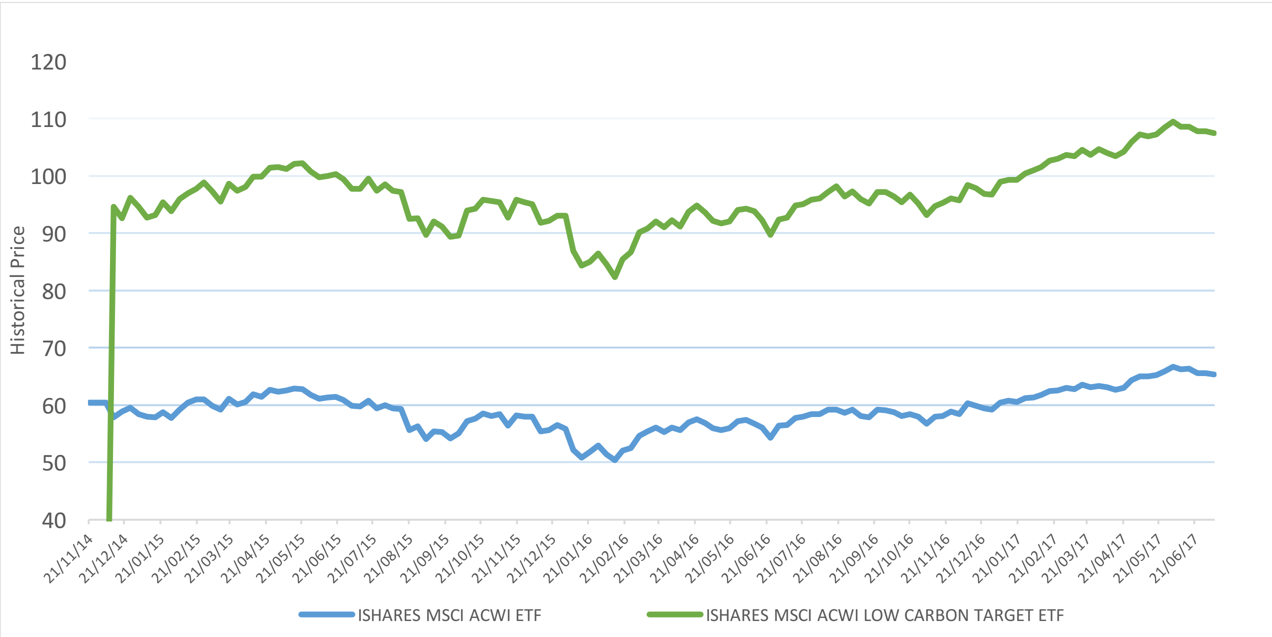
Lastly, the increasing consciousness about climate change issues has prompt socially responsible investors' desire to modify their portfolio holdings primarily through pledges to decarbonize portfolios, divest fossil fuel companies or disclose carbon footprints (Hildebrand and Winshel, 2016).

The speed of the energy transition and investors' time horizons have been so far the main determinants for assessing climate risks and opportunities. On the one hand, if reaction to climate change occurs at a slow pace, regulatory risks would be alleviated in the short term but significant physical risks would emerge in the long run. On the other, if action is undertaken too suddenly, negative effects originating from regulatory and technological risks would be hard to deal with in the short run. In addition, investors' horizon plays a critical role at this stage; long-term investors are considered to be reasonably more affected by physical and technological risks, and by climate change's impact on economic growth in the longer term. On the contrary, short-term investors would suffer from unexpected impacts stemming from regulatory decisions (Hildebrand and Winshel, 2016).

Due to the permanent loss of capital that investors could bear as a consequence of climate related risks, modern portfolios should be constructed in a way that favours the integration of climate factors. Given nowadays issues, it is fundamental for investors to include climate change mitigation into their investment decisions, a choice which does not seem to compromise returns. The previous statement is supported by evidence in the market that shows how climate related benchmarks have been recently outperforming their regular counterparts.

Figure 5 below highlights the difference in performance between iShares[6] MSCI ACWI ETF and iShares MSCI ACWI LOW CARBON TARGET ETF. The former *"seeks to track the investment results of an index composed of large and mid-capitalization developed and emerging market equities",* while the latter tracks the results of equities with same features, although characterized by a lower carbon exposure with respect to the market's one (BlackRock, 2017).

Figure 5. **iShares Weekly Performance**



Source: DataStream (2012) *Thomson Reuters DataStream* [Online]. (Accessed: July 2017).

6 "iShares are the world's largest family of Exchange Traded Funds (ETFs), [managed by BlackRock]." They enjoy both the benefits of shares as well as those of ETFs. As shares, their liquidity back the easiness according to which they can be traded on an exchange, whilst as index funds they offer diversification benefits, possibility of market tracking and low expenses. (BlackRock, 2015).

2. Literature Review

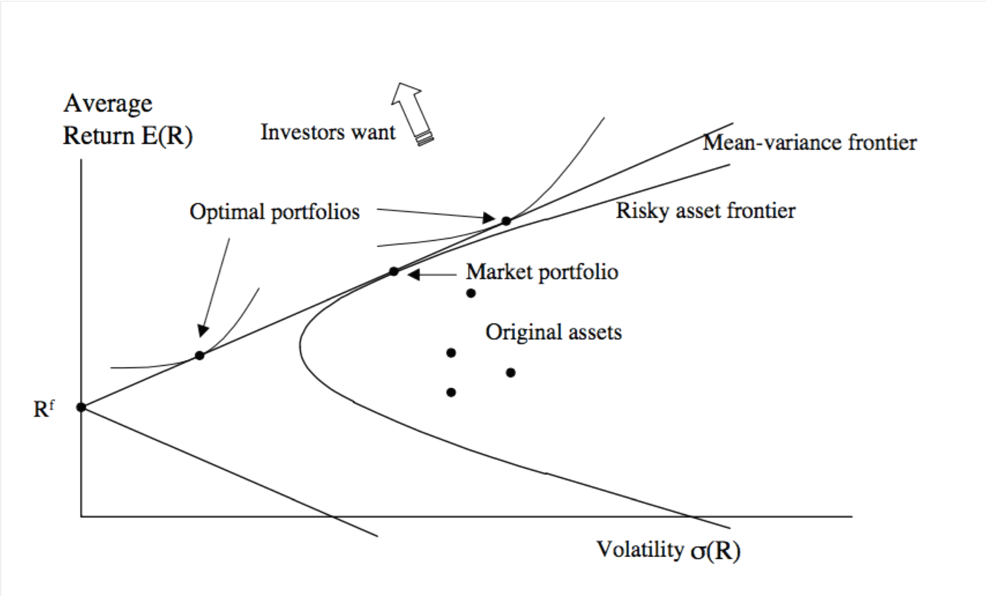
2.1. Traditional Portfolio Theory

Harry Markowitz is conceived as the founder of modern portfolio theory, following his first published essay "*Portfolio Selection"* (1952) and an extended work which was presented in the book, *"Portfolio Selection: Efficient Diversification"* (1959*)*. Based on the importance delivered to risk as a major determinant of investment and portfolio analysis, the brilliant contribution of Markowitz's work concerns the innovative concept of diversification applied to a number of securities incorporated within a portfolio, and their covariance relationships. As a matter of fact, his work provided evidence that diversifying across securities would generate a reduction in the overall risk of the portfolio, due to the elimination of the idiosyncratic risk.

To convey robustness to his theory, Markowitz had first to address and tear down the conventional belief that investors focused on the securities that would grant them the highest discounted expected returns in their portfolio selection's decision. Markowitz argued that an investor following this rule would end up selecting just one stock, namely the one that would maximize his expected returns. He was then able to state his mean-variance returns theory, according to which diversification is achieved by selecting and diversifying across the least correlated securities (Constantinides and Malliaris, 1995). He proved the mean variance portfolio theory by considering the two complementary principles of maximizing expected returns, holding constant variance, and minimizing variance, holding constant expected returns (Elton and Gruber, 1997). Based on this proposition, he developed the concept of an efficient frontier, that is a *"graphical representation of a set of portfolios that maximize expected return for each level of portfolio risk"* (Bodie *et al.*, 2014).

The mean variance frontier was constructed by first computing the mean variance frontier of all risky assets, and then the straight frontier generated from the risk-free rate. Optimal portfolios are those resulting from the tangency point of the investor's indifference curve and the mean variance frontier. Moreover, every portfolio that lies on the frontier results from the combination of risky assets and the risk free rate, thus each investor ends up holding the market portfolio, and the only implied decision concerns how much of it to hold (Cochrane, 1999). Inherently, an investor chooses an optimal portfolio, which suits his risk-return preferences, taking into account securities' co-movements rather than just considering their intrinsic characteristics. The resulting portfolio is one characterized by the same level of expected returns, but characterized by less volatility (Elton and Gruber, 1997). Alternatively, an investor compares the risk and returns associated to several portfolios and then chooses the one that delivers the highest expected returns for a given level of risk *"*[Indeed], *the* *mean-variance model establishes a direct and proportional relationship between risk and return"* (Dhankar and Kumar, 2006).

Figure 6. **Mean-Variance frontier**



Source: Cochrane, J.H. (1999) 'Portfolio Advice for a Multifactor World', *National Bureau of Economic Research.*

Modern portfolio theory is based on the consideration of just the first two moments of a distribution, namely mean and variance, whilst neglecting the possibility that further moments could bias the optimal outcomes resulting from the theorem. Tobin (1958) engaged in finding some necessary conditions, either related to investors' utility function or to returns' distribution, which would allow the mean-variance theorem to remain optimal [7] (Constantinides and Malliaris, 1995). Among others, Lee (1977), Kraus and Litzenberger (1976) developed alternative portfolio theories in which further moments of distributions were taken into consideration.

[7] Tobin dealt with the problem from a macroeconomic perspective, as opposed to the microeconomic one that could be associated to Markowitz's theory. He constructed his theory following the Keynesian inverse relationship between the demand for cash balances and the rate of interest, by considering the behaviour of the decision-making units of the economy. The aim is to prove that the the theory of risk-avoiding behaviour has potential to become a basis for liquidity preferences. The analysis is built on the assumption that an investor has the possibility of choosing among just two assets: cash and "consols". The former is always assumed to deliver a zero yield, whilst the latter involves a risk of capital gain or loss. The higher the amount of consoles' investments, the higher the risks undertaken by the investor and, in turns, the higher the expected returns he requires. Next, he formulates a two-asset portfolio selection problem by assuming away investor's subjective probability distribution. He argued that the parameters' choice depends on the form of the utility function considered; therefore, he justifies his focus on the mean and standard deviation because of the adoption of a quadratic utility function. Finally, his theory has the empirical advantage of explaining diversification, as the same investor holds both cash and "consols", meanwhile providing a more logical foundation for liquidity preferences. (Tobin, 1958).

Despite several contributions, the mean variance approach has prevailed as the foundation of modern portfolio theory primarily due to the large data requirements it places on investors, and the inability of other theories, built on further moments', to convey an optimal portfolio resulting to be more desirable than the one identified through the mean variance analysis (Elton and Gruber, 1997).

One of the underlying assumption of Markowitz's portfolio theory is that investors consider mean and variance of returns for each asset as well as covariances between assets' pairs, over a single period. By all means, the investor's problem is a multi period one in nature, thus many authors as Mossin (1969), Fama (1970), Hakannson (1970,1974) and Merton, (1990) attempted to address and solve the issue by providing extended theories. Their results convey the idea that, under a suitable set of assumptions, the multi-period problem can be solved as a sequence of single-period ones. Yet, the optimal portfolio to which utility maximization points is likely to be different from the one that could result from a single period optimization, as the investors would have indeed different utility functions based on the time period taken into consideration in the maximization problem. Merton (1990) addressed the issue by considering a continuous timeframe, in which portfolio selection and consumption investments problems are solved concurrently. His findings largely support the discrete-time period results, yet discovering that investors need to select portfolios to hedge the risk of the possible change in state variables, in an intertemporal continuous time framework (Elton and Gruber, 1997).

2.2. Green Investments

The importance that climate change has achieved in the last decades has prompt the growth of sustainable investments, which indeed are characterized by the integration of the above mentioned climate change issues in portfolio selection. The relationship between environmental and financial performance has largely been studied, although some limitations in terms of empirical evidence have emerged, as the latter is characterized by a strong dependency with respect to the variables chosen as indicators of environmental and financial performance.

Despite the more widespread knowledge of green funds, the trend of focusing on green asset classes themselves is a relatively new phenomenon. Accordingly, in terms of literature it is possible to designate a distinction between green equity and green fixed income considerations (Inderst *et al.,* 2012).

The equity class has been the main focus of green investments so far. In particular, most of the attention has been devoted to the relationship between firms' social and environmental performance

and their effect on the firms' stock prices. Similarly, another topic which has caught attention concerns the relation between the firms' responsible investing activities and portfolio performance.
What emerges from previous studies is that portfolios' returns are, on average, higher when environmental and social features are take into consideration.
For instance, Derwall *et al.* (2005) provided evidence supporting the benefits of considering environmental criteria in the individuals' investment processes. Contrarily to conventional investment theory insights, they found out that labelled "eco efficient" stock portfolio, comprehensive of large capitalization companies, outperformed a less efficient portfolio for the period under evaluation. Moreover, Statman and Glushkov (2005) investigated the extent to which bending portfolios towards stocks of rated high social responsible companies was a beneficial strategy for investors characterized by environmental and social preferences. As a result, they found out that such strategy provided investors with an advantage with respect to conventional investors in the period under consideration. In addition, they considered the opposite approach, namely avoiding the inclusion of stocks of rated low responsible companies in their portfolios; findings showed that this sort of action would put investors at a disadvantage with respect to conventional ones. The latter result seems to convey the idea that Socially Responsible Investments might prevail in the future and that they certainly provide some additional returns in the present, yet the transition still requires not to shun completely non-socially responsible securities.

Empirical studies assessing the impact of the green features on fixed income securities have been very limited so far. This has been due to many reasons including the fact that green investments have been directed in principle towards other types of instruments, that the dynamic and relatively new environment of the green bonds market, determined by numerous movements in supply and demand for those securities, has made it hard to assess the impact of particular green features, and, lastly, the lack of a comprehensive regulation and commonly accepted standard governing green issuances.
The major field of interest for green bonds characteristics has been the assessment of a green bond premium. The first analysis in regards, carried by the OECD in 2015, estimated that green bonds' features are identical to those of conventional bonds of the same issuer, on the issue date, because investors are not willing to pay a premium for holding a green security.
Further studies have contributed in broadening the available literature by focusing on the green bond premium in the secondary market and have reached conflicting results. On the one hand, Barclays (2015) and Bloomberg (2017) pointed to a negative green bond premium, which could be justified by the lower market volatility implied by those type of bonds or by the oversubscription characterizing the green bond market stemming from mismatches in supply and demand. On the other hand, a report of HSBC (2016) that manages to highlight cases of both negative and positive green

bond premia, suggest that it would be a mistake to consider the existence of negative green bonds premium as a methodical and regular one. Accordingly, a study performed by Karpf and Mandel (2017) aiming at investigating the yield term structure of green and conventional US municipal bonds for the same issuers in the US, provided evidence that a statistically significant spread between green and brown bonds exists. Nevertheless, the difference in mean characteristics between the two types of bonds arises due a less favourable valuation of green bonds, as compared to their counterpart, in the market. Thus, there seems to be a higher penalisation in the market for green over brown bonds, suggesting the idea, that if this was not the case, the spread between green and brown bonds would undoubtedly be lower.

3. Theoretical Framework

3.1 Utility Functions

This subchapter is provided to illustrate the form of the utility functions which the empirical analysis conducted in the next chapter originates from. The rationale for the determination of two different utility functions lies in the fact that two different types of investors are taken into consideration, one with standard mean-variance preferences and one characterized by green ones.

3.1.1 Mean-Variance Preferences

The broad amount of literature, research and empirical studies have confirmed the result that risky assets are associated to higher expected returns in the marketplace. Consequently, a portfolio is more attractive to investors when it is associated with higher returns and lower risk. However, given the inverse relationship established between the two features, the choice concerning the optimal portfolio is not straightforward. The main decision depends upon the degree of risk aversion that characterizes subjectively each investor; this will determine the rate at which one would trade risk for higher returns. The utility function is a tool that was conceived with the objective of assessing a rank for competing portfolios based on risk and returns considerations. Accordingly, a higher utility is associated with portfolios that offer more attractive risk-returns profiles (Bodie and Kane, 2014).
A commonly accepted and used utility function is the following,

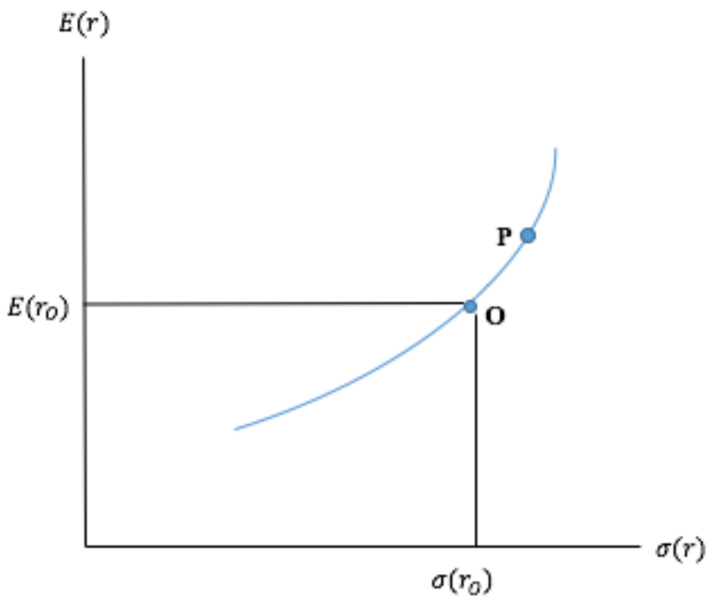
$$U = E(r) - \frac{1}{2} A\sigma^2 \tag{3.1.1}$$

where U is the utility level, $E(r)$ is the level of expected returns, σ^2 is the variance of returns and A is the coefficient representing the degree of risk aversion of each investor. Finally, $\frac{1}{2}$ is just a factor of scaling convention. The utility function here considered is a quadratic one, concave, which entails $U'(\cdot) \geq 0$ and $U''(\cdot) \leq 0$, and with any derivative with order higher than the second one equal to zero. This leads to the consideration of just the mean and variance of wealth as the determinants of the utility level.

The amount by which the variance of risky portfolios lowers the utility level for an investor depends on A. Based on individual characteristics referring to the level of risk one is willing to undertake, it is possible to distinguish between different type of investors. Accordingly, a risk averse investor is one who prefers and decides to hold portfolios that are associated with positive risk premia. An investor shaped by this type of features is one who accepts lower returns, as they realize at a lower risk. Another type of investor is the risk neutral one, who is essentially indifferent to risk when valuing different investment opportunities. Consequently, a risk-neutral investor will consider solely the expected rate of returns of the alternatives he is provided with during his decision making process. Finally, a risk lover investor is the one that enjoys engaging in gambling and fair games. As a matter of fact, he would be willing to accept higher risk for investments that have a relatively low expected return (Bodie and Kane, 2014).

After having assessed the degree of risk aversion for the investor, the following rule is applied in the determination of equally attractive portfolios for such investor. Accordingly, portfolio A is said to dominate portfolio B if $E(r_A) \geq E(r_B)$ and $\sigma_A \leq \sigma_B$, with at least one strict inequality. As a consequence, if an investor undertakes a choice that leads him to hold a riskier portfolio, then it must be the portfolio is compensating him with higher expected returns. This can be seen in Figure 7. below, that suggests all portfolios lying on the indifference curve are equally attractive for the investor. Indeed, each one of portfolios under consideration delivers to the investor the same utility level (Bodie and Kane, 2014).

Figure 7. **Indifference Curve**



Source: Bodie, Z., Kane, A. and Marcus, A.J. (2014) *Investments.* 10th edn. New York: McGraw Hill

3.1.2 Green Preferences

The purpose of this section is to investigate what happens to portfolio composition whenever green preferences are addressed. It seems sensible to first understand how preferences for "greenness" can affect investors' investment decisions. In order to explain some reasons for the choice behind green investment, coping with the widespread appearance of such types of instruments in the global market, it is relevant to start from the choices faced by individuals.

The first assumption that needs to be made, is that some individuals are willing to accept lower portfolio's expected returns if these entails portfolios are endowed with some green assets. Nevertheless, it is precisely this green feature that provides investors with a higher utility value. Therefore, an investor who is assumed to have green preferences will always choose to invest in the green instrument if a conventional "brown" one provides him with the same amount of expected returns, ceteris paribus. The terms brown and green are here used to trace and magnify the difference between the two types. Nevertheless, brown investments do not necessarily have to be bad for the environment, simply they are not as good and provided with climate standard certifications as their rivals, the "green".

In order to comply with the theoretical implications of the mean-variance preference utility functions presented in Section 3.1.1, the study focuses on the distinction between green and brown returns. Therefore, the "green" utility function here considered takes the following form:

$$u = (R_B + \vartheta R_G) - \frac{1}{2} A\sigma^2 \tag{3.1.2}$$

where R_B represent the returns from brown investments, whilst R_G returns from green investments. The parameter which is here introduced and whose aim is to capture preferences towards green investments is ϑ. This term is assumed to be $\theta > 0$ for *green* investors, and $\theta = 0$ for conventional *brown* investors. How much the individual is willing to invest in green securities depends on the subjective size of ϑ.

3.2. The Model

The model upon which the empirical analysis is carried is the Markowitz's mean-variance model, that is a two-dimension portfolio optimization problem, based on risk and expected returns. Risk represents the volatility of returns and is computed through the variance, or standard deviation, while expected returns are computed using the arithmetic mean of returns. Numerous criticisms have been moved towards the use of variance as a measure of risk, given its inability to assign different weights to deviations on either side of the mean. Despite several measures of risk have been proposed, from semi-variance to Value at Risk, the model under consideration uses standard deviation as a measure of risk as by considering all-wealth investments and assuming normality, it turns out to be an appropriate measure of risk (Bodie and Kane, 2014).

The mean variance model can be formulated as one in which the objective function consists of minimizing the portfolio risk, given returns are above a certain threshold, R_{min}; that is,

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j \sigma_{ij} \tag{3.2.1}$$

subject to

$$\sum_{i=1}^{n} R_i w_i \geq R_{min} \tag{3.2.2}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{3.2.3}$$

$$w_i \geq 0, i = 1, \dots , n \tag{3.2.4}$$

Alternatively, the model could be stated as maximizing portfolio's expected return, for a given maximum level of portfolio's acceptable risk, σ_{max}:

$$max \sum_{i=1}^{n} w_i R_{i,} \tag{3.2.5}$$

subject to

$$\sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j \sigma_{ij} \ll \sigma_{max} \tag{3.2.6}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{3.2.7}$$

$$w_i \geq 0, i = 1, \dots , n \tag{3.2.8}$$

The identical constraints imposed in the dual problem here considered (3.2.3, 3.2.4, 3.2.7 and 3.2.8) represent the total amount of wealth available to the investor and the no short sales condition, respectively. It seemed sensible to provide such assumption in this type of optimization problem given the constraints associated with obtaining such position in the real bond market.

Given E_iR_i, the expected return of security i, and given w_i ,the amount of investment allocated to financial instrument i, then the expected return of a portfolio is:

$$ER_p = \sum_{i=1}^{n} w_i E_i R_{i,} \tag{3.2.9}$$

where

$$\sum_{i=1}^{n} w_i = 1 \tag{3.2.10}$$

Nonetheless, computing and assessing the expected return of a security is complicated, thus a simpler method that entails computing the total return on a security is usually undertaken. The return on a security is calculated as the average of daily, weekly, monthly or annual returns:

$$R_i = \frac{1}{n}\sum_{i=1}^{n} \frac{V_1 - V_o}{V_o}, \tag{3.2.11}$$

where, R_i is the average return of security i, V_1 and V_0 are the selling and buying price of the security, respectively, and n is the number of periods analysed.
As stated in the foregoing introduction, the model uses standard deviation as a measure of risk. The risk of a security i is computed according to the following formula which is used to compute the variance:

$$\sigma_i^2 = \frac{1}{n}\sum_{i=1}^{n} (R_{it} - \bar{R}_i)^2 \tag{3.2.13}$$

where R_{it} is the return of a financial instrument in period t and $\bar{R}_i$ is the average expected return on security i. Subsequently, the standard deviation is then computed as the squared root of the variance.

The following formula is the one employed for the computations of the portfolio's expected returns

$$ER_p = W^T R = [w_1 \quad \dots \quad w_n] \begin{bmatrix} E_{(r1)} \\ \vdots \\ E_{(rn)} \end{bmatrix} \tag{3.2.14}$$

where,

W represents the vector of weights of the individual securities in the portfolio, and

R represents the vector of the individual annualized returns of the portfolio's assets.

Moreover, the variance of the portfolio is computed according to $\sigma_p^2 = W^T SW$, where W is again the vector of the weights, and S is the variance-covariance matrix. The latter was computed according to the following formula

$$S = \frac{1}{n-1} \sum_{i=1}^{n} (R_i - \bar{R})(R_i - \bar{R})'. \tag{3.2.15}$$

Finally, the standard deviation of the portfolio is the main variable of attention, as it is the one upon which the optimization problem is resolved.

It is computed as $\sigma_p = \sqrt{W^T SW} =$

$$\left[[w_1 \quad \dots \quad w_n] \begin{bmatrix} \sigma_{11} & \cdots & \sigma_{1n} \\ \vdots & \ddots & \vdots \\ \sigma_{n1} & \cdots & \sigma_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \right]^{1/2} \tag{3.2.16}$$

4. *Empirical Analysis*

The empirical analysis presented in this thesis is structured in two parts. The first one concerns a mean variance analysis of a portfolio, that entails the assessment of the efficient frontier and the optimal weights allocation arising from selected target returns. To assess the impact of green bonds on portfolio selection, three green bond indices have been selected as possible additional investment opportunities. On the basis of their statistical properties and past performance, the Global Green Bond Index has been selected as the one to include in the mean variance analysis. The portfolio composition as well as the changes to which the mean variance efficient frontier is subject are analysed and discussed. After having assessed optimal portfolios resulting from the unconstrained optimization problem, a further mean variance analysis is conducted by considering two different types of green investors, who are assumed to retrieve a higher utility value from green investments. The portfolio's risk and returns, as well as the optimal weights are evaluated by considering a utility function that entails a parameter ϑ, whose aim is to identify green preferences. Accordingly, the value of ϑ is assumed to be zero for a brown investor, whilst it is positive for a green investor. The portfolio's properties and the asset allocation arising from the mentioned analysis are computed and analysed in detail.

The answer to why global investors would substitute conventional brown investments for green ones in this first transition phase we are currently experiencing, cannot be entirely supported by a "green consciousness" developed by investors themselves. Despite the support granted by governments, institutions and states in favour of green bonds investments as a tool to deal with climate change, it must be that these green securities are endowed with some characteristics providing investors with adequate returns. Nevertheless, it is not possible to neglect the fact that green investments are those in line with nowadays commitments to a more sustainable word and that therefore could play a strategic and primary role in both the current and future financial scenario. As a matter of fact, a large number of markets around the planet have undertaken actions aimed at achieving green objectives. To support and encourage the growth of the green market, these green investments should become economically viable for those participating in the market; then, being characterized by features which are attractive for risk-averse investors, investments in the green sector would automatically be promoted from the market itself.

The main question is thus whether green instruments are capable of offering the best possible risk-return trade off to investors and, at the same time, outperform their brown counterparts.

4.1 Data and Specifications

The analysis conducted in this thesis focuses mainly on bonds and equity as it is, to my knowledge, among the first works trying to assess the importance of green bonds, proxied by green bond indices. In addition, it includes a commodity index, in order to allow the consideration of a more diversified portfolio. The three green bond indices considered in the following analysis are the Bloomberg Barclays Global Green Bond Index, the S&P Green Bond Index and the Bank of America Merrill Lynch Green Bond Index. Monthly data for the three indices have been retrieved from Bloomberg and refer to the period ranging from April 2014 to November 2017. The aim is to use green bond indices as proxies for green investments and investigate whether they are able to provide investors with a desirable amount of returns, comparable to those of conventional brown bonds. The latter are represented in the analysis by the Bloomberg Barclays Global Aggregate Bond Index Unhedged and the US Aggregate Bond Index. Data for the latter two indices were retrieved from Bloomberg as well. In addition, investments in shares are evaluated through the MSCI World Index, a global equity benchmark, the MSCI EM ASIA[8] and the S&P BRIC 40[9] Indices. Finally, investments in commodities are represented by the S&P GSCI Index, the first major investable commodity index (S&P Dow Jones Indices). [10]

The reason underlying the choice of global indices is consistent with the aim of selecting multicurrency indices, expressed in US dollars and unhedged against currency movements.

Furthermore, the reason behind the selection of just a few indices is coherent with the view that, by being one of the first studies trying to assess the impact of green products into the portfolio optimization process, it would have been easier to establish and evaluate the obtained results. Accordingly, by keeping the choice simple and clear, the benefits, features and limitations of the green bond indices selected for the analysis have been thought to be more straightforwardly detected.

Given the major importance that green issuances have gained in the past few years, enabling an astonishing growth of the green bond market, green indices have been developed and have become widespread in the financial scene. This has been mainly due their ability to tear down barriers as the lack of specific knowledge on green bonds' types and the lack of fully understanding the risk and the performance they generate. As of March 2014, Solactive AG launched the first green bond index, the

[8] Captures large and mid cap representation across 9 emerging market countries, that are China, India, Indonesia, Korea, Malaysia, Pakistan, the Philippines, Taiwan and Thailand. With 572 constituents, the index covers approximately 85% of the free float-adjusted market capitalization in each country (MSCI Emerging Market Asia, 2018)

[9] Providing exposure to 40 leading companies from the emerging markets of Brazil, Russia, India and China through liquid stocks trading on developed market exchanges (S&P Dow Jones Indices)

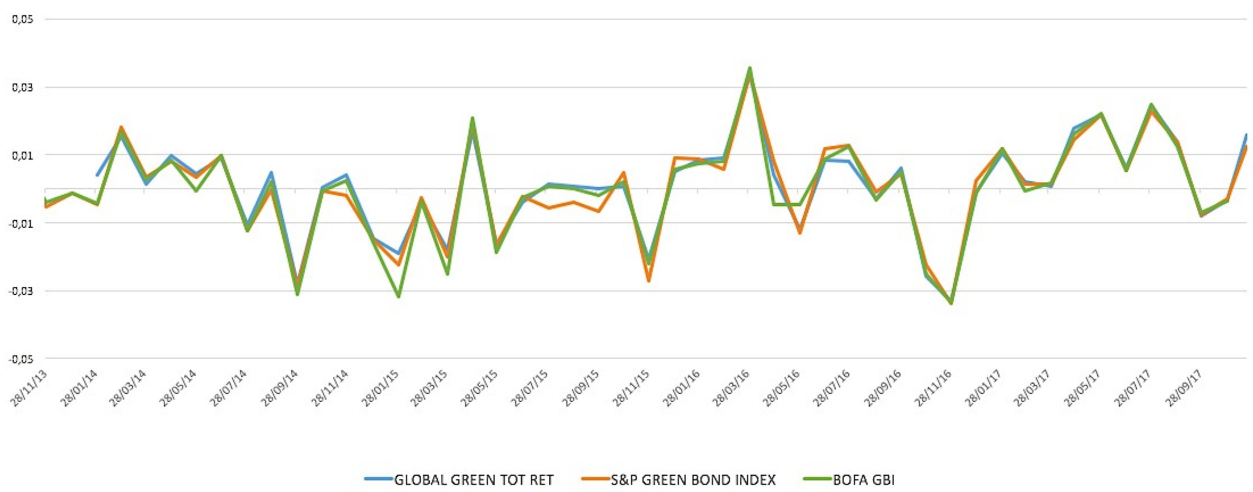
[10] The index comprises the most liquid commodity futures and provides diversification with low correlations to other asset classes (S&P Dow Jones Indices)

first one in the market able to provide exposure to green bonds. Since then, a number of rating agencies and financial institutions developed their own green bond indices, as the S&P Green Bond Index and the S&P Green Project Bond Index, which were launched in July 2014, followed by the Green Bond Index conceived by Bank of America Merrill Lynch in October 2014 and the one arising from a collaboration between MSCI and Barclays in November 2014, who elaborated a family of green bonds related indices.

The indices differ in terms of eligibility criteria for what concerns green bonds to be included. Table A.1 in the Appendix contains a summary of the main properties and characteristics of the green bonds indices considered in this study. What is surely interesting and compelling is the fact that the increased consideration and elaboration of green indices is a sign of the importance and growing maturity of the green bond market, which may become one of the main actor of the future financial scene.

As a matter of fact, it seems interesting to deliver some more specific information concerning the performance of the green bond indices that were chosen. An analysis of the past performance was conducted by considering the trend of the indices' monthly Total Return Index, which should be able to convey a more accurate illustration of the indices' performance and which is illustrated in Figure 8 below.

Figure 8. **Monthly Returns of Selected Green Bond Indices**



Source: Bloomberg (2017)

As perceived from the graph, which dates back to the beginning of the year 2014, the three indices show a similar pattern in terms of returns, oscillating between values of approximately -0.03 to 0.03. Among the three the one that appears to be slightly more volatile is the Bank of America Merrill

Lynch Green Bond Index. This could be due the fact it invests in bonds of corporate and quasi-governments issuers, but excludes securitized and collateralised securities, as opposed to the other two green bond indices which allow for the inclusion of the just mentioned investments.

The Green Bond Index that has proved to be the best performer among the ones considered in the study is the Bloomberg Barclays Global Green Bond Index, as can be seen from Table 1 below, that reports the mean and standard deviation of the three green bond indices for the period January 2014 to November 2017. As a matter of fact, the Global Green Bond Index is the one characterized by a higher annualized mean compared to the other two indices. This is in line with the nomination it received as the "Best Green Bond Index available in the market" in the Green Bond Awards of 2017. For what concerns the volatility of the three indices, which is here expressed in terms of standard deviation, the one that has shown the greatest volatility in the period under study is the Bank of America Merrill Lynch GBI, even though it is slightly greater than the other two.[11].

Table 1. **Descriptive Statistics of Green Bond Indices**

	Annualized Mean (%)	**Annualized Standard Deviation (%)**
Global GBI	1.909	5.248
S&P GBI	-0.237	5.185
Bank of America Merrill Lynch GBI	-0.501	5.316

On the basis of these considerations, the Global GBI was selected as the green bond index to be included in the mean variance analysis performed in this study. As the objective of the thesis consists of identifying any potential benefits, expressed in terms of diversifications and returns, derived from the inclusion of green figures in the portfolio, selecting the best performer seemed to be the choice more likely to be undertaken by a conventional investor, if provided with the opportunity of investing in selected green securities.

Table 2 reports the summary statistics for the assets incorporated in the portfolio which the mean variance analyses of the thesis refers to. On the bonds' side, the Global Aggregate Bond Index appear to be in line with the results obtained from the three green bond indices, though it is characterized by

[11] GBI from here on is refers to the Green Bond Index

both lower mean and standard deviation in comparison to the Global Green Bond Index. Furthermore, the US Aggregate Bond Index has outperformed the other two bond indices, though it is probably due the impressive growth experienced by the US market especially in the past twelve months. For what concerns the equity side, that in the portfolio under evaluation comprises the MSCI World Index, the MSCI Emerging Markets Asia Index and the BRIC 40 Index, it reasonably experiences a completely different pattern with mean and standard deviations that are considerably higher.

Table 2 **Statistical Summary of selected Asset Classes**

Variable	**Label**	**Annualized Mean (%)**	**Annualized Standard Deviation (%)**
US Aggregate Bond Index	US AGG	2.265	2.863
Global Aggregate Bond Index	GLOBAL BOND	0.979	4.754
Bloomberg Barclays Global GBI	GLOBAL GREEN	1.909	5.248
MSCI World	MSCI	8.084	9.983
MSCI Emerging Markets Asia	MSCI EM ASIA	4.788	14.384
BRIC 40	BRIC	5.731	16.563
S&P GSCI	GSCI	-14.999	17.651

Finally, the commodity index, the S&P GSCI, results to be the more volatile, with a standard deviation of 17.65%. Despite the negative mean of returns it has realized, there are several reasons underlying the inclusion of such asset class in the portfolio, the most important being the higher degree of diversification it brings to the overall portfolio. The negative trend experienced by the index can be traced back to the financial crisis of 2008, which was responsible for halving the value of the index in just a few months as of July 2008 (S&P Dow Jones Indices LLC). Clearly, from a macroeconomic perspective, the crisis led to a decrease in the demand for commodities as a consequence of the reduction in economic possibilities to which worldwide states were subject. For instance, it is enough to consider China, which passed from a growth pace of 12% per year, prior to the financial crisis, to one of approximately 6-7% per year in the years that followed. The slowdown in the Chinese economy impacted the extent to which it could sustain its former demand which of course was linked to the commodities' sphere as well. Lastly, given the historical negative correlation between stocks and commodities, the inclusion of the latter could result to be a winning strategy should the financial markets experience a structural tendency shift in the upcoming years.

Whenever descriptive statistics are considered, it is useful and recommended to consider the correlation among different asset classes. Table 3 represents the pairwise correlation between the monthly returns of the bond indices, the green bond index, the equity indices and the commodity index.

Table 3 **Correlation Matrix**

	US AGG	GLOBAL BOND	GLOBAL GREEN	MSCI	MSCI EM ASIA	BRIC	GSCI
US AGG	**1**	0.5053	-0.1608	0.7227	0.2754	0.3194	-0.9064
GLOBAL BOND	0.5053	**1**	0.5859	0.4665	0.3823	0.4277	-0.1531
GLOBAL GREEN	-0.1608	0.5859	**1**	0.2201	0.3982	0.4082	0.4142
MSCI	0.7727	0.4665	0.2201	**1**	0.7045	0.7233	-0.5509
MSCI EM ASIA	0.2745	0.3823	0.3982	0.7045	**1**	0.9705	-0.0165
BRIC	0.3194	0.4277	0.4082	0.7133	0.9705	**1**	-0.0633
GSCI	-0.9064	-0.1531	0.4142	-0.5509	-0.0165	-0.0633	**1**

Evidence from the correlation matrix supports the idea that including the S&P GSCI as an investment choice delivers benefits to the portfolio, indeed the lowest the correlation, the greater the potential benefits derived from diversification. As a matter of fact, the latter is negatively correlated with all the other asset classes, expect from the Global Green Bond Index, with which, however, has a tenuous positive correlation. Moreover, the correlation between the bond indices and the equity indices referring to BRIC or Emerging Market Asia is low. A slightly higher correlation between two asset classes seems to occur between the US Aggregate Bond Index and the MSCI World Index, that could supposedly be justified by the fact that most of the MSCI's top ten constituents are US Companies or Financial Institutions and that the Unites States represent the 59.49% of the Index's country weights (MSCI Inc., 2017). Lastly, the Global Green Bond Index appears to be negatively correlated with the US Aggregate Bond Index, and to have low positive correlation with the other indices. Not surprisingly, the highest correlation it endorses is the one with the Global Aggregate Bond Index, probably due the fact they are both related to global features.

4.2. Methodology

In order to determine the optimal portfolio, the total return index values were used to evaluate the monthly returns for each of the portfolio's assets, as proposed by Equation 3.2.11. For a more sensible analysis, the monthly returns were then converted into annualized ones. Furthermore, the annualized variance-covariance matrix was also assessed, returning the values of the assets' variances on the main diagonal and the covariances between each pair of securities in the other entries of the matrix. The variance-covariance matrix is displayed in Section B of the Appendix.

When addressing the portfolio optimization problem, the main decision to which an investor is subject concerns the allocation of the assets, that is the proportion he or she would be willing to allocate to the different asset classes. As the decision boils down to selecting the portfolio belonging to the feasible set that offers the best risk-return combination, it seems sensible to provide some insights on how this feasible set is constructed.

In order to analyse the risk-return trade-off faced by investors, it is fundamental to highlight the distinction between risky and risk-free assets. The sole entity that can issue almost risk-free assets is the government, almost as these securities are still endowed with a little amount of risk. Nonetheless, 3-moths Treasury Bills are commonly accepted and regarded as risk-free assets, given their short-term nature (Bodie, Kane and Marcus, 2014).

According to Bodie, Kane and Marcus (2014), whenever an investor has already selected the risky portfolio, then the major choice one is concerned with is the capital allocation, that is, determining the amount of wealth to be allocated to the risky portfolio and to the risk-free asset. Denoting by r_f the risk free rate, by r_P the return on the risky portfolio P, and by $E(r_P)$ and σ_P its expected return and standard deviation, respectively, the risk premium associated to the risky assets results to be $E(r_P) - r_f$. On the one hand, assuming 1 the disposable amount of wealth available to the investor, denoting by y and, reasonably, $(1 - y)$ the proportion of wealth invested in the risky portfolio and in the risky free-asset, the rate of return on the complete portfolio equals

$$r_C = yr_P + (1 - y)r_f \tag{4.2.1}$$

Hence, the portfolio's expected rate of return has the following form

$$E(r_C) = yE(r_P) + (1 - y)\, r_f = r_f + y\left[E(r_P) - r_f\right] \tag{4.2.2}$$

which implies that the portfolio earns a fixed rate equivalent to the risk free rate and the risk premium associated to the risky portfolio. On the other hand, assumed the investment in the risky portfolio is **y**, the standard deviation of the portfolio will be equal to the standard deviation of the risky portfolio times the weight associated to the risky asset in the specific portfolio. Therefore, the complete portfolio' s standard deviation takes the following form

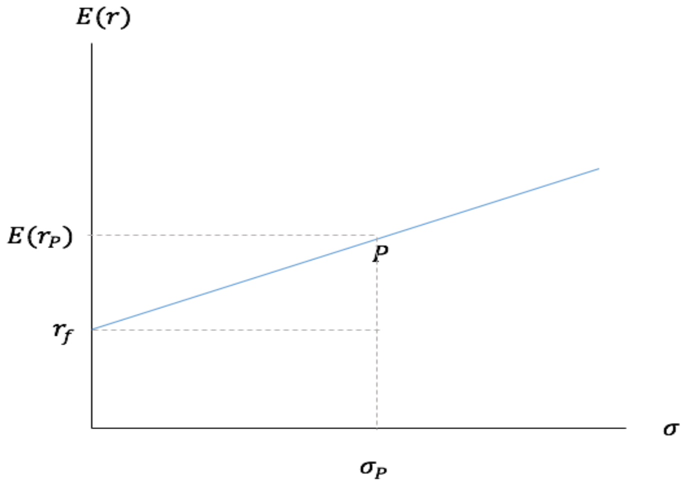
$$\sigma_C = y\sigma_P \tag{4.2.3}$$

The capital allocation procedure allows to plot the different portfolios, arising from the decision of how much to invest in the risky portfolio, in the expected return-standard deviation plane that is shown in Figure 9 below. Despite extreme cases entailing investments in either the risky or the risk-free asset, interesting portfolios are those that fall in between, that is, midrange portfolios in which y takes values in between 0 and 1. Those are the portfolios lying on the blue line, that is the Capital Allocation Line (CAL), connecting r_f to P in Figure 9. To get the equation for the Capital Allocation Line, the term $y = \frac{\sigma_C}{\sigma_P}$ is obtained from Equation 4.2.3 and it it subsequently substituted in Equation 4.2.2, that is the one referring to the expected return of the complete portfolio. Accordingly, the expected return of the complete portfolio appears as a straight line with intercept r_f and slope equal to

$$S = \frac{E(r_P) - r_f}{\sigma_P} \tag{4.2.4}$$

The slope of the line is known as the Sharpe Ratio and it expresses the increase in expected return per unit of standard deviation (Bodie, Kane and Marcus, 2014).

Figure 9. **The Investment Opportunity Set**



Source: Bodie, Kane and Marcus, 2014

Figure 9 above depicts the set of all feasible portfolios available to the investor resulting from different values of y, which is also commonly recognized as the investment opportunity set.
As an investor is provided with a limited set of possible investment choices, it seems sensible to explain how the optimal portfolio is selected when facing the CAL. The feature that determines the choice of the optimal portfolio is the trade-off between risk and returns. Certainly, the individual coefficient of risk aversion plays a key role, as different capital allocation choices result from the subjective risk aversion each investor is subject to. Intuitively, risk-averse investor will tend to invest the majority of their wealth onto risk-free assets, as opposed to risk-lover investor who would rather allocate a larger amount of wealth into risky assets. The way in which investors decide upon the allocation of wealth between risky and risk-free assets stems from the utility maximization problem, which, considering the standard mean variance preferences' utility function, takes the following form:

$$Max\ U = E(r_C) - \frac{1}{2}A\sigma_C^2 = r_f + y\left[E(r_P) - r_f\right] - \frac{1}{2}Ay^2\sigma_P^2 \qquad (4.2.5)$$

Given the concave property of the utility function, its value will increase up to a maximum point, after which it will start to decrease again. Setting the first derivative equal to zero will lead to finding this maximum value, which is associated to an optimal proportion y^* invested in the risky asset. [12]
The solution to the maximization problem is

12 $\frac{\delta U}{\delta y} = \left[E(r_P) - r_f\right] - 2\frac{1}{2}Ay\sigma_P^2 = 0$, bringing the term $Ay\sigma_P^2$ to the LHS yields $Ay\sigma_P^2 = E(r_P) - r_f$. Solving for y leads to the determination of the optimal position in the risky asset.

$$y^* = \frac{E(r_{P)} - r_f}{A\sigma_P^2} \tag{4.2.6}$$

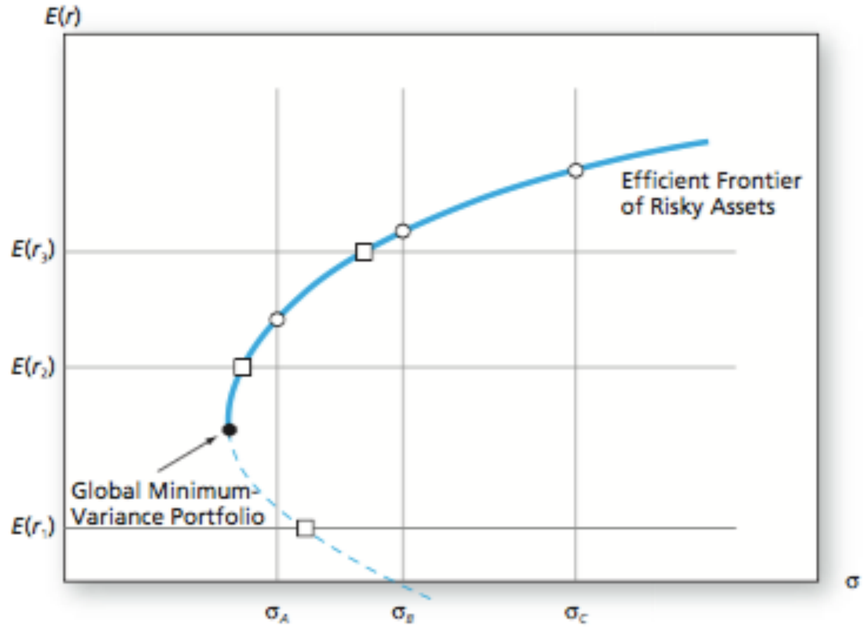
that highlights the inverse relationship between the optimal proportion of wealth invested in the risky asset and the degree of risk aversion and the level of portfolio's risk, whilst it points to a direct relationship between the optimal amount of wealth invested in the risky asset and the risk premium associated to the risky asset. The identification of the optimal portfolio follows straightforwardly. Considering the investor's indifference curves, the optimal portfolio will lie on the tangency point between the highest possible indifference curve and the Capital Allocation Line. Hence, the optimal choice for y^* and thus the identification of the optimal portfolio will depend on the risk aversion coefficient and the Sharpe Ratio (Bodie, Kane and Marcus, 2014).

The mean-variance portfolio optimization model applies to the case of many risky assets and a risk-free one. The optimization procedure consists of three step: the risk-return analysis, the selection of the optimal portfolio of risky assets obtained from the weights' allocation yielding the highest Sharpe Ratio and, lastly, the choice of the appropriate complete portfolio attained by mixing the risk-free asset with the optimal risky portfolio (Bodie, Kane and Marcus, 2014).

Equations 3.2.14 and 3.2.16, specified in the theoretical framework, allow to determine the risk-return opportunities available to investors, which will result in the efficient set of portfolios, and that will be graph as the efficient frontier of risky assets. The frontier depicts the lowest possible risk that can be attained for a given level of portfolio's expected returns. The efficient portfolio set is represented in Figure 10 below.

Optimal portfolios are those lying on the efficient frontier, from the global minimum variance portfolio onwards. Indeed, the lower portion of the frontier is referred to as the inefficient frontier, as for a given level of risk there exists a portfolio that yields highest expected returns. The individual assets constituting the portfolio will all lie to the right of the frontier, supporting the findings that portfolios composed of a single asset are inefficient and that diversifying across assets returns higher portfolios characterized by higher expected returns and lower risk (Bodie, Kane and Marcus, 2014).

Figure 10. **The Efficient Portfolio Set**



Source: Bodie, Kane and Marcus, 2014

A remarkable point, which is extremely important to consider given the study proposed by thesis, concerns the individual constraints each investor faces while considering investment opportunities. The constraint that is usually applied in portfolio optimization problems is the one prohibiting short sales. Nevertheless, specific constraints may be imposed on the basis of peculiar investments' desire by single investors. For instance, additional constraints, which have been introduced more often in recent times, are those referred to as socially responsible constraints, that are, constraints preventing investments in countries or industries perceived as ethically or politically undesirable. The latter are constraints that limit investment opportunities and hence are usually associated to costs which come in the form of lower Sharpe Ratios, although this cost is assumed to be willingly borne by investors as it expresses a cause they firmly support (Bodie, Kane and Marcus, 2014).

The second step of the portfolio optimization problem entails considering the risk-free asset, as this allows to identify the portfolio that maximizes the Sharpe Ratio and that is therefore associated to the steepest Capital Allocation Line, the one that is tangent to the efficient frontier exactly in the point *P*, where the optimal risky portfolio lies. Finally, the last step of the problem consists of the appropriate choice, undertaken by the single investor, between the optimal risky portfolio and the risk-free asset (Bodie, Kane and Marcus, 2014).

4.3 Evaluation of Results

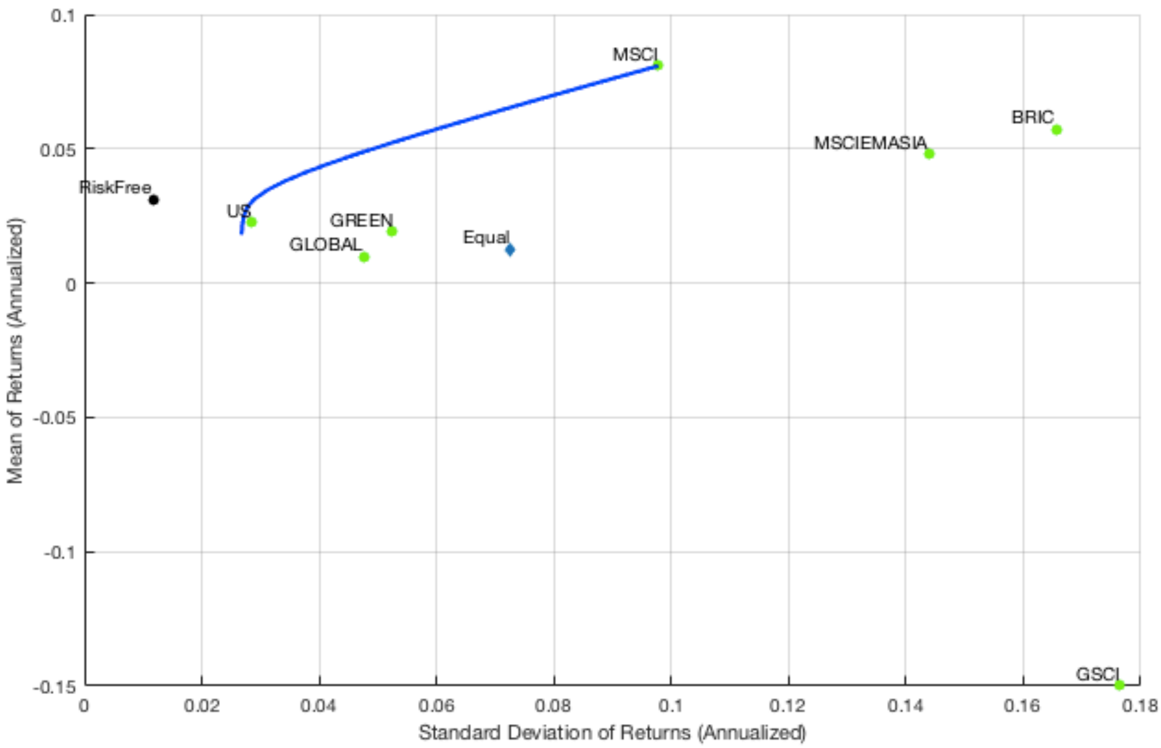
The following section presents the evaluation of results stemming from two distinct optimization problems. The former consists of a portfolio optimization in which the constraints imposed are those on the weights of the single asset classes and the no short sales setting. This first problem will be referred to as the unconstrained one in the rest of the study. The latter, which is instead defined as the constrained optimization problem, is characterized by the introduction of an additional constraint on the specific weight assigned to the green asset belonging to the optimal portfolio. The green constraint is intended to determine a distinction between standard and green investors, the latter being designated by favouring investments into green asset classes. To summarize what already presented in the chapter entailing the consideration of the theoretical framework, these green preferences are captured by the introduction of a parameter ϑ in the utility function which, in the empirical analysis here conducted, is assumed to be positive and greater than selected positive amounts to be able to represent the value added retrieved from green investments. The same parameter is assumed to be equal to zero for a brown investor. Hence the purpose of the constrained optimization problem is to investigate what happens to the portfolio composition, and the implied risks and returns, whenever a distinction among green and brown investors is framed.

The seven asset that have been included as possible investment choices for both types of optimization problems are the US Aggregate Bond Index, the Global Aggregate Bond Index, the Global Green Bond Index, the MSCI World Index, the MSCI Emerging Market Asia Index, the BRIC 40 Index and, lastly, the S&P GSCI Index. The mentioned indices were selected with the aim of originally constructing a portfolio that was already somehow diversified in terms of different asset classes among which to allocate wealth. As a matter of fact, the choice ranges from bonds to equity, of both developed and emerging markets, to commodities. In addition, it comprehends a Green Bond Index that has been chosen according to its specific statistical properties, namely mean and standard deviation. Extending the asset allocation choice beyond that of bonds and equities, and thus granting investors the opportunity to consider alternative asset classes as commodities and green bonds, here proxied by the two indices, has been performed with the hope of lowering total portfolio volatility, increasing total portfolio returns, or generating some combinations of higher returns and lower volatility.

4.3.1. Unconstrained Optimization

The first analysis performed resolves around a mean variance analysis conducted by employing the standard mean variance utility functions underlying such computations. The 3-Months Treasury Bill Rate was chosen as the risk-free rate implied for the portfolio's computations.
Figure 11 below displays the efficient frontier of risky assets as well as the single asset allocations in the expected returns-standard deviation plane.

Figure 11. **Efficient Frontier of Risky Assets**



The first thing worth noting is that the bond indices are quite similar one another, being all characterized by lower returns and lower standard deviation in comparison to the equities' indices. The Global Green Bond Index seems to be slightly riskier than the Global Aggregate Bond Index, and it is accordingly positioned a little bit more on the right. The equity indices are all characterized by higher returns and higher risks, among which the riskier one results to be the BRIC 40 Index. Finally, the S&P GSCI Index is the one characterized by the highest degree of risk and that is associated to the lowest and even negative amount of returns. The figure supports the findings that combinations of different assets yield better results, in terms of risks and returns, with respect to investments is single securities, which are indeed all located on the righter side of the efficient frontier. Finally, the dot labelled *Equal* represents the equally weighted portfolio, that is, the one in which each asset is assigned the same weight.

It seemed sensible to compute the range of risks and returns among all portfolios lying on the efficient frontier. Results from the computations yielded a range of annualized risk in between 2.68% and 9.78%, whilst the annualized returns' level ranged in between 1.80% and 8.08%. Hence, these values were paramount in the determination of targeted returns allowing a meaningful comparison for the asset allocation identifying the optimal portfolios yielding the desired levels of returns. Table 4, 5, 6 and 7 below refer to the asset allocation and the portfolios' risk associated to specified level of required returns.

Table 4. **Asset Allocation for 5% Targeted Returns**

Target Return: 5% (Annualized)	
US AGGREGATE	52.99%
MSCI	47.01%
Annualized Stdv	**4.91%**

Table 5. **Asset Allocation for 7% Targeted Returns**

Target Return: 7% (Annualized)	
US AGGREGATE	18.62%
MSCI	81.38%
Annualized Stdv	**8%**

As it can be seen from the two tables above, investors whose degree of risk aversion is lower, and who are accordingly more willing to undertake risks, do not retrieve any benefits from the consideration of the Global GBI. Presumably, the reason is related to the fact that selecting the US Aggregate Bond Index, which is endowed with lower risk with respect to the Global GBI, would allow investor to allocate a greater amount of wealth onto the MSCI World Index compared to the amount it would receive if the instead the asset allocation would be constituted by just the MSCI Index and the Global GBI. As a matter of fact, the latter would be also associated with a higher portfolio's risk.

As the purpose of the analysis is related to the value added brought by the inclusion of green bonds, here proxied by the Global GBI, it was presumed to be more reasonable to shift the focus towards portfolios requiring lower amounts of expected returns in this unconstrained optimization problem. Indeed, as the returns, and hence risks, increase, the percentage allocated to equity rather than bond's indices increases accordingly. This is perceivable from the considerable difference in asset allocation in the optimal portfolios resulting from targeted returns of 3 and 5% respectively. Indeed, whenever higher level of returns is expected, the only two assets to which wealth is allocated are the US Aggregate Bond Index and the MSCI World Index. As a matter of fact, the green bond index does not provide investors with diversification opportunities whenever they require higher level of returns, though this is line with the fact that an investor with such kind of preferences will be willing to allocate a greater portion of his investments into the equities' indices. Contrarily, whenever a 3% target return is imposed, the asset allocation consists of additional assets entering in the optimal portfolio's composition, which are the Global GBI and the MSCI EM ASIA Index. These findings are showed in Table 6 below.

Table 6. **Asset Allocation for 3% Targeted Returns**

Target Return: 3% (Annualized)	
US AGGREGATE	81.95%
GLOBAL GREEN	4.83%
MSCI	12.70%
MSCI EM ASIA	0.52%
Annualized Stdv	**2.84%**

In line with the just mentioned results, those portfolios for which investments in the Global GBI could materialize are those to which a higher focus is directed. Hence, the additional scenario entailing a target return of 2.5% was considered. Results from the optimization are reported in Table 7 below.

Table 7. **Asset Allocation for 2.5% Targeted Returns**

Target Return: 2.5% (Annualized)	
US AGGREGATE	83.55%
GLOBAL GREEN	9.13%
MSCI	5.77%
MSCI EM ASIA	1.00%
S&P GSCI	0.55%
Annualized Stdv	**2.70%**

These results are of extreme importance for the aim of the thesis. It is worth noting that for investors requiring a low level of returns, the Global GBI emerges as an investment opportunity.
On the one hand, it could be argued that this would be a straightforward consequence of requiring a lower level of expected annualized returns, which implies increasing the percentage allocated to bonds. The latter is a fair and reasonable thought. Yet, what seems to emerge from the analysis here conducted is that the green index delivers higher diversification benefits with respect to its comparable Global Aggregate Bond Index. As a matter of fact, the latter does not belong to the optimal portfolio requiring a targeted return of either 2.5 or 3%. Hence, as the two indices belong to the bond category, it must be that the Global GBI is superior for some intrinsic characteristics it possesses. This conveys the idea that green assets' potential has been somewhat recognized in the market. For green assets have emerged in the past couple years, this result seems to cope with an initial modest approach undertaken by investors, who happen to be among the firsts investing in such type of security.

Moreover, it is relevant to underline that the investor considered in this first part of the analysis is someone for whom holding some green assets does not convey additional utility values. Thus, it seems reasonable to believe that the situation for investors who retrieve a value from the greenness of the portfolio could deliver even better results with respect to the ones achieved here. To conclude, results emerging from the asset allocation reasoning seems to suggest that the introduction of more and more green features into portfolios would be plausible.

To conclude, results emerging from the previous analysis suggest that there are some benefits associated to green investments, even though these are negligible for the portfolios examined. The rationale behind these results could be due the fact that the benchmark portfolio here considered is already highly diversified, thus implying that space for further diversification is likely to be extremely reduced. Then, it may be the case that green bonds are able to offer more diversification opportunities, and thus greater benefits, if they are introduced in portfolios endowed with different and/or additional asset classes. Another scenario could be the one in which green bonds provide retail investors, who usually hold less diversified portfolios, with greater diversification benefits compared to the ones generated here. Finally, given the recent spread of green bonds investments, the time length under study may not be enough to suggest and provide reliable information in terms of diversification benefits provided, thus underestimating the correlation that could be much stronger between green bond indices and different asset classes and that could promote the inclusion of such type of securities in the decisions making process undertaken by investors.

4.3.2 Constrained Optimization

Based on the results gathered from the previous part, the constrained optimization problem here conducted focuses particularly on the Global Green Bond Index in trying to assess the impact of its inclusion into the portfolio of a green investor. The rationale behind this choice is coherent with the idea that the chosen index is the one that, in the current scenario, is the most attractive and thus reasonably capable of delivering the highest benefits.

The aim of the optimization procedure consists of identifying the optimal portfolios for green-type investors. An important assumption that needs to be made, concerns the distinction among the existence of different types of green investors themselves. Accordingly, the parameter ϑ, highlighting preferences towards green assets, is assumed to undertake higher values the strongest investors' green preferences are. The assumption is fundamental for distinguish between *moderate* and *high green* investors. Hence, the proportion of wealth invested in the Global GBI increases the stronger the green preferences exhibited by the investor. The constraint representing investors' willingness to hold a certain proportion of green assets will be useful for an attempt to determining the value of these green preferences' ϑ.

Moreover, it is crucial at this stage to consider that we are still experiencing a transition phase towards a greener economy and greener financial world, which implies that the proportion of wealth allocated into the Global GBI could not embody extremely high values. Nevertheless, if one analyses the scenario for a usual mean-variance preferences' investor, it can be seen that for low level of risks and returns, a determinate amount of wealth is already allocated to the green index. Thus, the latter has been used as the starting point to evaluate how the asset allocation changes based on the specific green preferences that will be subsequently considered. Accordingly, the type of investor who would be eager to invest in the optimal portfolios arising from the unconstrained analysis is assumed to be the brown, or *low-green* investor, one who does not gain any additional value stemming from the green investment itself.

Briefly summarising the findings of the previous analysis, low targets of expected returns already imply some investments in the Global GBI, whilst higher amounts of target returns, which in the previous analysis were assessed at 5 and 7% (annualized), did not result in allocations which entailed green bonds. Hence, the constrained optimization analysis here presented aims at understanding what would be the portfolios' outcomes for green investors requiring substantial amount of expected returns. As stated above, it seemed sensible to distinguish between moderate and high green investors in order to establish some values according to which the analysis could be performed properly. Hence, a moderate green investor has been assumed to require a 5% investment in the Global GBI, whilst the high green investor would require at least a 10% of wealth allocated to the Global GBI. By all means, these constraints will be imposed for the evaluation of optimal portfolios with target returns of 5% and 7%, that in the unconstrained optimization did not involve green investments.

The first asset allocation that is analysed, and which is exposed in Table 8 below, is the one referring to an optimal portfolio requiring 5% expected returns.

Table 8. **Asset Allocation for 5% Targeted Returns**

Target Return 5%			
Moderate Green		***High Green***	
US AGGREGATE	47.69%	US AGGREGATE	42.39%
GLOBAL GREEN	5.01%	GLOBAL GREEN	10%
MSCI	47.30%	MSCI	47.61%
Annualized Stdv	**4.99%**	**Annualized Stdv**	**5.06%**

The first noticeable thing is that the changes applied to the portfolio's allocations occur at the expenses of the US Aggregate Bond Index. Yet, this could be expected as the requirement of moderately high expected returns suggests a significant part of wealth be allocated to the MSCI World

Index. Accordingly, for a moderate green investor the weight decreases from 53% to 47.69% whilst for a high green investor it decreases to approximately 43%. Another consequence stemming from the consideration of green constraints is that the overall risk of the portfolio slightly increases. Indeed, the annualized risk for a brown portfolio of 5% returns not endowed with any constraint, and whose values are reported in Table 4, was 4.91%. In the optimal portfolios incorporating the Global GBI the standard deviation is slightly higher, 4.99% and 5.06% for a moderate and high green investor respectively, even though the difference is presumably negligible as it is justified by the investors' willingness to hold those specific securities.

The changes in the optimal allocations and the results on the annualized risk of the optimal portfolios associated to a 7% target return are coherent with those of the Target 5% Portfolio and are summarized in Table 9 beneath. As a matter of fact, the percentage allocated to the US Aggregate Bond Index decreases from 18.62% to 13.32% and to 8.02% in the case of a moderate and high green investor, respectively. Moreover, the increase in the annualized standard deviation is quite negligible in the moderate green investor's case, as it sets at a value of 8.07%, a value that is considerably close to the one associated to the conventional brown portfolio of 8%. The increase is a little ampler and yield an annualized risk of 8.17% in the case of a high green investor, although it could be considered to be still close and comparable to the other two just mentioned. None the less, the slight increase realizes as a consequence of delivering more weights to the green assets, thus highlighting the fact that green investors are presumably aware and willing to take on this little additional risk to have green features in the portfolios they hold.

Table 9. **Asset Allocation for 7% Targeted Returns**

Target Return 7%			
Moderate Green		***High Green***	
US AGGREGATE	13.32%	US AGGREGATE	8.02%
GLOBAL GREEN	5%	GLOBAL GREEN	10%
MSCI	81.68%	MSCI	81.98%
Annualized Stdv	**8.07%**	**Annualized Stdv**	**8.17%**

If green investors truly acted and reasoned in the way it is assumed here, then portfolios generating a considerable amount of expected returns could be constructed in a way that allows the inclusion of green features and that would yield investors outcomes that are quite similar to those they could have obtained by investing in a conventional brown portfolio.

A final interesting discussion is the one concerning the Sharpe Ratios resulting from the portfolios here analysed. First of all, the Sharpe Ratios resulting from the unconstrained optimization problem in the case of 5 and 7% targeted returns are, respectively:

$$S_{5\%} = \frac{0.05 - 0.0312}{0.0491} = 0.382 \qquad\qquad S_{7\%} = \frac{0.05 - 0.0312}{0.080} = 0.485$$

Additionally, the Sharpe Ratios for either levels of required returns were assessed for both the moderate and high green investor. Thus, the Sharpe Ratios for portfolio's entailing 5% returns are

$$Moderate\ Green\colon\ S_{5\%} = 0.377$$
$$High\ Green\colon\ S_{5\%} = 0.371$$

while those for the 7% target return portfolio are

$$Moderate\ Green\colon\ S_{7\%} = 0.480$$
$$High\ Green\colon\ S_{7\%} = 0.474$$

What can be deducted from the computations above, is that "*going green*" comes at a cost, in terms of lower Sharpe Ratios. This is line with previously conducted studies suggesting that ethical investments are usually associated to lower Sharpe ratios with respect to their conventional counterpart. None the less, it is interesting to look at the problem from another perspective, which is in line with the aim of thesis. The difference in Sharpe ratios could indeed reflect the value a green investor assigns to the green investment itself. Thus, if for a conventional mean-variance preferences' investor the difference is perceived as a cost, it could correspond exactly to the specific value-added brought by green bonds that is retrieved in the form of a higher utility by the green investor. Accordingly, if one focuses on the difference, what emerges is that for both the 5% and 7% Target Returns Portfolios, the difference in the Sharpe ratios for a brown and a moderate green investor is 0.005, whilst that between a brown and a high green investor is 0.011. Hence, we see that, in this specific context, a moderate green investor presumably has a parameter ϑ of 0.005, a sort of ethical-green return which is not embodied in the financial one. Moreover, the value of ϑ for a high green investor is reasonably higher and, in the specific context here analysed, results to be equal to 0.011. Despite the impossibility to establish the real value for this ϑ, perceived to capture ethical "green" preferences, it seems reasonable to support the view that green investors retrieve a higher level of utility when assets characterized by green features are included in the portfolio they hold. Thus, the aim consisted in exploring a path for assessing whether benefits of green bond could be realized for an investor with standard mean-variance preferences, or whether a strong desire for the green was needed to sustain the possibility of holding such portfolio. What seems to emerge from the analysis is that, currently, investors who do not care personally about the greenness of their portfolios and who require considerably high amount of expected returns, would hardly shift towards green investments given the slight more risk they would be asked to undertake. Nevertheless, for greener oriented investors, who are willing to face challenges linked to the uncertainties of the market and thus favour investments in green securities, there are some benefits in terms of diversification and ethical returns that would make them willing to do so and opt for the green portfolios.

For what concerns the limitations arising from this second part of the analysis, they are mostly referred to the consideration of the parameter ϑ, and the values it is assigned. Indeed, the values of ϑ assumed in the evaluations are exclusively applicable for the specific context considered here, in terms of portfolio's composition. Accordingly, if the S&P Global Green Bond Index or rather the Bank of America Merrill Lynch Green Bond Index were considered, the values of ϑ would probably be different from those obtained when evaluating the Bloomberg Barclays Global Green Bond Index. Moreover, the assumption which allows to conduct a meaningful analysis of the problem is the one on the values to which the inequality constraints refer, namely a moderate investor requiring 5% of investments in the Global GBI and a high one, requiring instead 10% of wealth allocated of the Global GBI. The reason for the assumption of such values is coherent with the fact that a complete shift toward a green portfolio is something that will probably be achieved in future times, after the benefits of green bonds will be visible to the majority of investors. Hence, choosing other values for the constraints would have yielded different results. In addition, if additional assets or indices had been included, the benefits derived from the inclusions of green financial products could have emerged in a different fashion, in terms of values of ϑ for which a given desirable allocation into the green bond index would realize.

To conclude, the aim of the study was to gather some insights about the properties of green bond indices and the effects brought by their inclusion into investors' portfolios. Thus, if one focuses on the scenarios proposed in the empirical analysis, the outcomes seem to suggest that there are some differences originating from the types of investors identified, and that trying to develop mechanisms apt at quantitatively assess green preferences would be an interesting path to undertake in current times during which the green bonds market continues to grow further.

Conclusions

The considerable importance that climate change has achieved in the latest years has been mirrored by the extremely rapid growth that has characterized the green bond market since its first appearance in the financial world. This market has seen the development of specific financial products, green bonds, issued with the aim of providing solutions to threats and issues posed on the environment by climate changes. The market has developed in times where increasing regulation has been imposed by government, states and climate-policymakers for limiting the threats that have been damaging our planet. This increasing regulation has raised the transparency of the green market which, in turns, has prompted the issuances and investments in green products.

The mean-variance analyses performed in the study attempts both in understanding whether green bonds are likely to be included in a portfolio, first evaluating a choice for a mean-variance preferences' investor, and then by considering green investors. Results from an initial statistical analysis seems to suggest that, among the three green bond indices initially selected, the one that would most likely be considered by a conventional mean-variance preferences' investor is the Bloomberg Barclays Global Green Bond Index. As a matter of fact, the latter is the green bond index that has been characterized by the higher annualized mean for the period considered in this study.

Results from the unconstrained optimization problem suggest that the Global Green Bond Index is a component of the optimal portfolio whenever low levels of portfolio's annualized returns are considered. Despite the straightforward intuition that low levels of returns would prescribe a higher proportion of investments in the bonds' side, what is actually interesting is that the green index delivers higher diversification benefits with respect to its comparable Global Aggregate Bond Index. As a matter of fact, the latter does not belong to the optimal portfolio requiring a targeted return of either 2.5 or 3%. This conveys the idea that green assets' potential has been somewhat recognized in the market. Contrarily, if higher levels of returns are required, the Global Green Bond index does not appear to be one of the possible investment choices. Indeed, investors whose degree of risk aversion is lower, and who are thus more willing to undertake risks, do not retrieve any benefit from the consideration of the Global GBI. What has emerged from the unconstrained analysis is that green bonds would be a good investment choice for investors requiring low levels of returns. Nevertheless, it is relevant to underline that the investor considered in this first part of the analysis is someone for which holding some green assets does not convey additional utility values. Thus, it seems reasonable to believe that the situation for investors who value the greenness of a portfolio could deliver better results with respect to the ones achieved here.

The second mean-variance analysis, also referred to as the constrained one, aims at comparing the asset allocation choices and the portfolio's risks and returns characteristics, when the difference comes from the type of investor considered. The way in which their decisions differ depends on the parameter ϑ, which is conceived as the one reflecting green preferences. The way in which these preferences have been assessed in the thesis consists of inequality constraints introduced in the optimization problem. The first assumption concerned the distinction between two types of green investors, a *moderate-green* one, who was assumed to require at least a 5% of wealth allocated to the Global GBI, and a *high green* investor requiring instead a 10% investment in the Global Green Bond Index. An explanation for why such values have been chosen is coherent with the fact that we are still experiencing a transition phase towards a greener economy and greener financial world, which implies that the proportion of wealth allocated into the Global GBI could not embody extremely high values. The aim of the constrained optimization analysis consists of understanding what would the portfolios' outcomes be for green investors requiring substantially higher amounts of expected returns.

The first thing worth noting when considering the asset allocation for a moderate and a high green investors' portfolio with 5% Target Return is that the changes applied to the portfolio's allocations occur at the expenses of the US Aggregate Bond Index. Yet, this could be expected as the requirement of moderately high expected returns suggests a significant part of wealth be allocated to the MSCI World Index. Another consequence stemming from the consideration of green constraints is that the overall risk of the portfolio slightly increases. Indeed, the annualized risk for a brown portfolio of 5% returns, not endowed with any constraint was 4.91%. In the optimal portfolios incorporating the Global GBI the standard deviation is slightly higher, 4.99% and 5.06% for a moderate and high green investor respectively, even though the difference is presumably negligible as it is justified by the investors' willingness to hold the specific green asset. Furthermore, the changes in the optimal allocations and the results on the annualized risk of the optimal portfolios associated to a 7% target return are coherent with those of the Target 5% Portfolio. None the less, the slight increase realizes as a consequence of delivering more weights to the green assets, thus highlighting the fact that green investors are presumably aware and willing to take on this little additional risk to have green features in the portfolios they hold.

The final analysis concerned the Sharpe ratios resulting from the 5 and 7% Target Portfolios for both the unconstrained and the constrained cases. What seems to emerge by the two analysis is that "*going green"* occurs at a cost, in terms of lower Sharpe Ratios. This is line with previously conducted studies suggesting that ethical investments are usually associated to lower Sharpe ratios with respect to their conventional counterpart. None the less, the difference in Sharpe ratios could indeed reflect the value a green investor assigns to the green investment itself. Hence, we see that, in this specific context, a moderate green investor presumably has a parameter ϑ of 0.005, a sort of ethical-green return which is not embodied in the financial one. Moreover, the value of ϑ for a high green investor is reasonably higher and, in the specific context here analysed, results to be equal to 0.011.

All things considered, the analysis here conducted does not seem to deliver strong results which are able to justify completely the growing interest for the green bond market. Moreover, for the negligible, but slightly positive results found in this study, it may be too early to perceive the benefits associated to green bonds inclusion into portfolio selection. Nevertheless, green bonds are a newly developed tool, which, in line with the increasing regulation and growth of the green market, will probably become an important tool in the future financial scene.

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Appendices

Appendix A

Table A.1: Characteristics of selected Green Bond Indices

	Bloomberg Barclays Global GBI	S&P GBI	Bank of America Merrill Lynch GBI
Launch Date	November 2014	July 2014	October 2014
First Value Date	1 January 2014	28 November 2008	31 December 2010
Track	Global Green Bond Market	Global Green Bond Market	Global Green Bond Market
Sector	Corporate, Government-related, treasury and securitized bonds	Corporate, government, multilateral issuers	Corporate, government, quasi-government issuers
Currency	Multi-currency	Any country/currency	Qualifying emerging market currencies
Weighting Scheme	Market-Value weighted	Market-Value weighted	Market-Value weighted
Green Criteria	Assessed against six MSCI defined eligible environmental categories[13]	Bonds must be flagged as "green" by CBI	Clearly designated use of proceeds with aim climate change mitigation or other environmental sustainability purposes
GBP/CBI alignment	Not explicit Broadly aligned with GBP	Aligned to CBI	Not explicit
Credit Quality	Investment-Grade Bonds [14]	Investment-Grade Bonds	Investment-Grade Bonds
Coupon Type	Fixed-rate	Fixed-zero, step-up, Fixed-to-float, Floaters	Fixed-rate or with temporary fixed schedule
Rebalancing Frequency	End of month	End of month	End of month
Calculation Frequency	End of day	End of day	End of day

[13] Alternative energy, energy efficiency, pollution prevention and control, sustainable water, green buildings and climate adaptation.
[14] Using the middle rating of Moody's, S&P and Fitch

Exclusion	Restrictions on proceeds use apply	Bills, inflation-linked, STRIPS	Restrictions on bond characteristics apply[15]

Appendix B

Table B.1: Annualized Variance Covariance Matrix

	US Aggregate	Global Aggregate	MSCI	Global Green	MSCI Em. Asia	GSCI	BRIC
US Aggregate	0.00024	0.00028	0.00004	0.00013	0.00003	-0.00023	0.00012
Global Aggregate	0.00028	0.00065	0.00037	0.00046	0.00031	0.00033	0.00063
MSCI	0.00004	0.00037	0.00276	0.00037	0.00177	0.00219	0.00278
Global Green	0.00013	0.00046	0.00037	0.00079	0.00030	0.00058	0.00065
MSCI Em. Asia	0.00003	0.00031	0.00177	0.00030	0.000579	0.00281	0.00580
GSCI	-0.00023	0.00033	0.00219	0.00058	0.00281	0.00899	0.00382
BRIC	0.00012	0.00063	0.00278	0.00065	0.00580	0.00382	0.00792

[15] Contingent capital securities, municipal securities, inflation-linked securities, equity-linked securities, legally-defaulted securities

LIBERA UNIVERSITÀ INTERNAZIONALE DEGLI STUDI SOCIALI

Department of Economics and Finance
Chair of Theory of Finance

Going Green:
Analysis of a Sustainable Portfolio

SUPERVISOR
Nicola Borri

CANDIDATE
Eleonora Mascelluti
676751

CO-SUPERVISOR
Federico Nucera

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Introduction

The continuous growth of the world population, the scarcity of resources and the environmental pressures are major determinants of the transition phase towards a greener and sustainable planet we are currently experiencing. Climate change is a fundamental concern that poses serious threats to the ecosystems in which we live and, in turn, to our present and future well being.
Nowadays, the importance achieved by climate change is having repercussions on many aspects, including the financial one, which is the main subject of the study. In the effort to reduce their carbon footprints, advanced economies have been suffering from a deficit of public infrastructure investments, whilst developing economies have lacked the possibility of providing access to modern services to their growing population. Accordingly, the ability to gather the right type of investments for the infrastructure sector is fundamental for the transition path. Climate policymakers have thus the responsibility of creating incentives to promote green growth and to encourage investments in sustainable projects from the private sector.

The increasingly importance of sustainable and environmental investments had its repercussions on financial markets as well, which have indeed become paramount to solve the climate challenge, by meeting the growing demand for low-carbon projects around the world. As a matter of fact, new financial tools aimed at directing capital to green projects have been developed, and are becoming widespread as the benefits they deliver have been progressively recognized. Debt securities have been used to finance low carbon and climate resilient infrastructures for a while now, yet it was only in 2007 that a market for bonds specifically designated as "green" has emerged. Green bonds appear to be a suitable candidate instrument, consistent with climate change mandates, to promote sustainable growth. Moreover, as the majority of developing countries is committing to maintain a fast pace of growth by investing in sustainable and renewable resources, green bonds have the potential to enable this growth by creating a bridge between the financial and the environmental scene.

1. The Green Bond Market

The quality of infrastructure is a vital component for a country's development, as it increases the chances to maintain a sustainable economic growth. Enormous level of infrastructure investments is needed nowadays to support economic growth and to cope with the necessity of providing basic needs to the growing population, especially in emerging countries where urbanization is advancing. According to a newly published OECD report, approximately USD 95 trillion of infrastructure investments are expected in the next 15 years, of which transport and energy represent 43% (OECD, 2017). The vast majority of contemporaneous infrastructures was designed specifically for a world able to provide abundant and cheap fossil fuels. Nonetheless, the emerging environmental threats have raised awareness about the necessity to invest in low-carbon climate resilient infrastructures to ensure a long lasting economic growth.

Governmental structural reforms in the field of climate policies, whose aim is to attract interests-aligned investments, are crucial for guiding countries in the low-carbon climate resilient process. On the one hand, the public sector fulfils a critical role in ensuring that infrastructure investments are supporting economic and climate-related issues. On the other, it is responsible for shaping an environment that favours the speed up of private investments into environmentally sustainable projects. Nevertheless, the substantial risk perceived when financing infrastructures has hampered the flow of private funds into infrastructure projects, especially in emerging countries. Moreover, political, regulatory, macroeconomic, business risks and, ultimately, climate change risk further hinder private investments. Several risk mitigations and financial approaches have been developed to cope with the above mentioned issues; financial tools range from guarantees and credit enhancement to currency hedging, whilst new instruments such as green bonds grant a reliable long-term funding basis for infrastructure projects.

Debt securities have largely been used to finance low carbon and climate resilient infrastructures, nonetheless it was only since 2007 that a market for bonds specifically designated as "green" has emerged. The main difference between a green bond and a conventional one concerns the use of the earmarked proceeds; indeed, green bonds are debt instruments issued with a commitment to finance exclusively eligible green projects and infrastructures. As a matter of fact, green bonds have been defined as fixed income financial instruments issued to raise capital with the purpose of backing climate or environmental projects. The specific use of the proceeds is what distinguishes a green bond from a regular one; namely the label "green" identifies a commitment to use the proceeds of the green bonds, the principal, in a transparent manner and exclusively for the financing of eligible green projects. The blurred scenario of the green bond market is what has hampered a sudden growth in the number of investments, as investors and issuers are highly concerned about the definitions and processes according to which a bond categorizes as green. Nonetheless, the willingness to bring greater clarity into the picture has boost the research upon standards and criteria applying to green bonds. For what concerns its development, the green bond market has grown significantly since the first issuance in 2007, with a boost in volumes occurring in 2013, as a result of the first corporate green bonds issued in the United States. Until 2016, a large part of the proceeds was allocated to renewable energy and energy efficiency, however the increased participation of development banks, corporates and municipalities has allowed to broaden proceeds' use to other sectors that include water, transport and waste management projects. As a matter of fact, during 2016 the total volume of green bonds issuance doubled with respect to the previous year, reaching an amount of USD 81.4 billion. The green bond market has kept its sustained pace of growth in 2017 and has broken new records, exceeding the USD 100bn mark. The relevant growth experienced by the green bond market in the latest year has been a major determinant for the consequent increase in size of the climate-aligned bond market, of which labelled green bonds account the growing share.

Given the importance achieved by climate change nowadays, and given the increased number of investors who are willing to take action against climate change, adapting portfolios to climate change seems to be a new trend which could affect the financial market scene. Although the majority of countries in the world is well aware of environmental issues and has been taking actions to deal with them, governments, investors and consumers have been much slower to recognized them, mostly due to behavioural biases. Indeed, both risks and opportunities which do not occur in the nearest future are likely to be underestimated, as individuals are not able to identify the significant impacts they could deliver in the longer period. However, as time passes by, these effects materialize and it becomes essential to consider climate change and to deal with its associated risks. Due to the permanent loss of capital that investors could bear as a consequence of climate related risks, modern portfolios should be constructed in a way that favours the integration of climate related figures.

2. *Literature Review*

Harry Markowitz is conceived as the founder of modern portfolio theory due the innovative concept of diversification which was the focus of the essay "*Portfolio Selection*" published in 1952. As a matter of fact, his work provided evidence that diversifying across securities would generate a reduction in the overall risk of the portfolio, due to the elimination of the idiosyncratic risk. To convey robustness to his theory, Markowitz had first to address and tear down the conventional belief that investors focused on the securities that would grant them the highest discounted expected returns in their portfolio selection's decision. He was then able to state his mean-variance returns theory, according to which diversification is achieved by selecting and diversifying across the least correlated securities (Constantinides and Malliaris, 1995). Inherently, an investor chooses an optimal portfolio, which suits his risk-return preferences, taking into account securities' co-movements rather than just considering their intrinsic characteristics. To conclude, an optimal portfolio is one that stems as the outcome of an optimization problem consisting of minimizing portfolio variance while keeping returns above a specified level. Despite the numerous criticisms that have been moved towards Markowitz's work, it still remains the most widely implemented procedure for portfolio optimization.

The relationship between environmental and financial performance has largely been studied, although some limitations in terms of empirical evidence have emerged, as the latter is characterized by a strong dependency with respect to the variables chosen as indicators of environmental and financial performance. With respect to green investments, it is possible to distinguish between between studies concerning the green equity side and those who rather focus on the green fixed income sphere. The equity class has been the main focus of green investments so far. In particular, most of the attention has been devoted to the relationship between firms' social and environmental performance and their effect on the firms' stock prices. Similarly, another topic which has caught the attention has been deemed to be the relation between firms' responsible investing activities and portfolio performance. Empirical studies assessing the impact of the green features on fixed income securities have been very limited so far. This has been due to many reasons including the fact that green investments have been directed in principle towards other types of instruments, that the dynamic and relatively new environment of the green bonds market, determined by numerous movements in supply and demand for those securities, has made it hard to assess the impact of particular green features, and, lastly, the lack of a comprehensive regulation and commonly accepted standard governing green issuances. Among the studies conducted, the more structured ones have been those whose primary objective was the identification of a possible green bond premium in the secondary market.

3. Theoretical Framework

Before considering the portfolio optimization model, it is fundamental to specify the forms of utility functions which are considered in this study and which the empirical analysis conducted in the next chapter originates from. The rationale for the determination of two different utility functions lies in the fact that two different types of investors are taken into consideration, one with standard mean-variance preferences and one characterized by green ones. First of all, the utility function is a tool that was conceived with the objective of assessing a rank for competing portfolios based on risk and returns considerations. Accordingly, a higher utility is associated with portfolios that offer more attractive risk-returns profiles (Bodie and Kane, 2014). A commonly accepted and used utility function is the following,

$$U = E(r) - \frac{1}{2} A\sigma^2 \tag{3.1}$$

where U is the utility level, $E(r)$ is the level of expected returns, σ^2 is the variance of returns and A is the coefficient representing the degree of risk aversion of each investor. Finally, $\frac{1}{2}$ is just a factor of scaling convention. Equation 3.1.1 refers to a traditional mean-variance preferences' investor.
In order to explain some reasons for the choice behind green investment, coping with the widespread appearance of such types of instruments in the global market, it is relevant to start from the choices faced by individuals. The first assumption that needs to be made, is that some individuals are willing to accept lower portfolio's expected returns if these entails portfolios are endowed with some green assets. Nevertheless, it is precisely this green feature that provides investors with a higher utility value. Therefore, a green utility function has been thought to have the following form:

$$u = (R_B + \vartheta R_G) - \frac{1}{2} A\sigma^2 \tag{3.2}$$

where R_B represents the returns from conventional brown investments, whilst R_G returns from green investments. The parameter which is here introduced and whose aim is to capture preferences towards green investments is ϑ. This term is assumed to be $\theta > 0$ for *green* investors, and $\theta = 0$ for conventional *brown* investors. How much the individual is willing to invest in green securities depends on the subjective size of ϑ.

The model on which the empirical computations of the study are based is the Markowitz's mean variance model, whose objective function consists of minimizing the portfolio risk, given the returns are above a certain threshold, R_{min}; that is,

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j \sigma_{ij} \tag{3.3}$$

subject to

$$\sum_{i=1}^{n} R_i w_i \geq R_{min} \tag{3.4}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{3.5}$$

$$w_i \geq 0, i = 1, \dots, n \tag{3.6}$$

Equations 3.5 and 3.6 represent the constraints referring to the total amount of wealth available to the investors and the no short sales condition, respectively.

To perform a meaningful risk-return analysis, consisting of the identification of the risk-return combination among the set of risky assets, the following methodology has been applied for estimating portfolio's returns, variance and covariance.

The following formula is the one employed for the computations of the portfolio's expected returns

$$ER_p = W^T R = \begin{bmatrix} w_1 & \dots & w_n \end{bmatrix} \begin{bmatrix} E_{(r1)} \\ \vdots \\ E_{(rn)} \end{bmatrix} \tag{3.7}$$

where,

W represents the vector of weights of the individual securities in the portfolio, and

R represents the vector of the individual annualized returns of the portfolio's assets.

Moreover, the variance of the portfolio is computed according to $\sigma_p^2 = W^T SW$, where W is again the vector of the weights, and *S* is the variance-covariance matrix. The latter was computed according to the following formula

$$S = \frac{1}{n-1} \sum_{i=1}^{n} (R_i - \bar{R})(R_i - \bar{R})'. \tag{3.8}$$

Finally, the standard deviation of the portfolio is the main variable of attention, as it is the one upon which the optimization problem is resolved.

It is computed as $\sigma_p = \sqrt{W^T SW} =$

$$\left[\begin{bmatrix} w_1 & \dots & w_n \end{bmatrix} \begin{bmatrix} \sigma_{11} & \cdots & \sigma_{1n} \\ \vdots & \ddots & \vdots \\ \sigma_{n1} & \cdots & \sigma_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \right]^{1/2} \tag{3.9}$$

4. Empirical Analysis

The empirical analysis presented in this thesis is structured in two parts. The first one concerns a mean variance analysis of a portfolio, entailing the assessment of the efficient frontier and the optimal weights allocation arising from selected target portfolios' returns. To assess the impact of green bonds on portfolio selection, three green bond indices have been selected as possible additional investment opportunities. On the basis of their statistical properties and past performance, the Global Green Bond

Index has been chosen as the one to include in the mean variance analysis. After having assessed optimal portfolios resulting from the unconstrained optimization problem, a further mean variance analysis, which is referred to as the constrained one, is conducted by considering two different types of green investors, a moderate green and a high green one, who were assumed to retrieve higher utility levels stemming from green investments.

Table 1 below reports the summary statistics for the assets incorporated in the portfolio which the mean variance analyses of the study refer to.

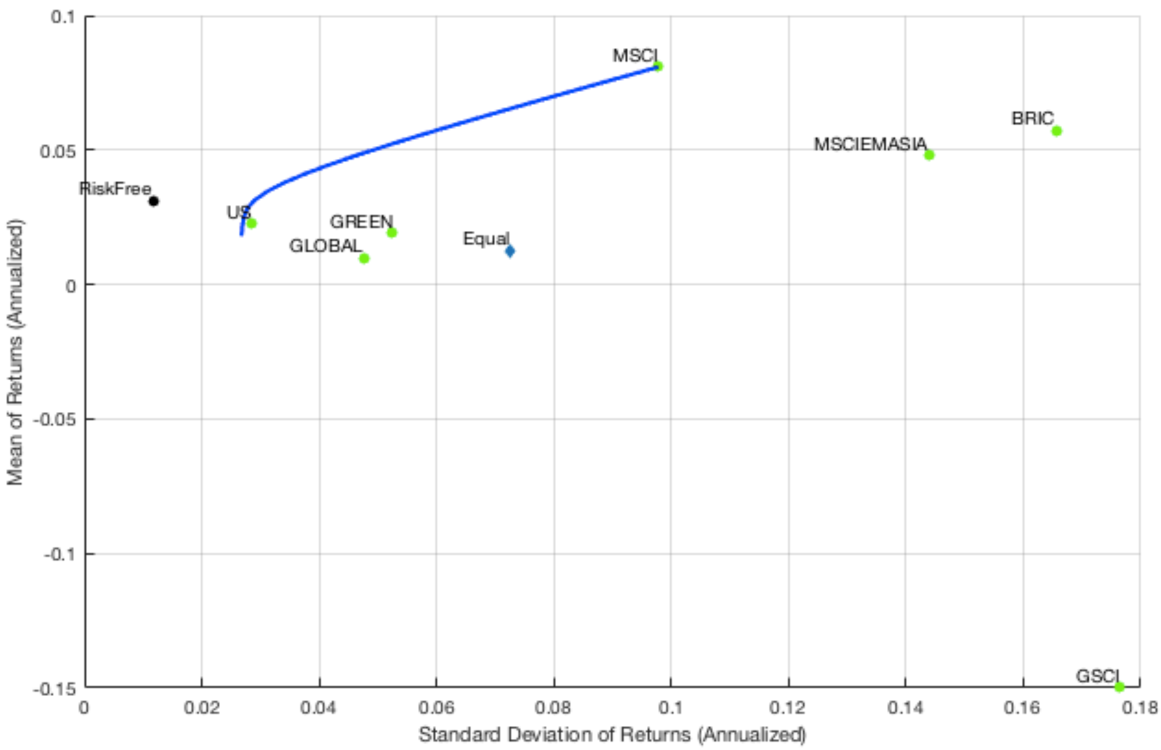
Table 1 **Statistical Summary of selected Asset Classes**

Variable	**Label**	**Annualized Mean (%)**	**Annualized Standard Deviation (%)**
US Aggregate Bond Index	US AGG	2.265	2.863
Global Aggregate Bond Index	GLOBAL BOND	0.979	4.754
Bloomberg Barclays Global GBI	GLOBAL GREEN	1.909	5.248
MSCI World	MSCI	8.084	9.983
MSCI Emerging Markets Asia	MSCI EM ASIA	4.788	14.384
BRIC 40	BRIC	5.731	16.563
S&P GSCI	GSCI	-14.999	17.651

On the bonds' side, the Global Aggregate Bond Index appear to be in line with the statistical properties of the Global Green Bond Index, though it is characterized by a lower mean and standard deviation. Furthermore, the US Aggregate Bond Index has outperformed the other two bond indices, though it is probably due the impressive growth experienced by the US market especially in the past twelve months. For what concerns the equity side, that in the portfolio under evaluation comprises the MSCI World Index, the MSCI Emerging Markets Asia Index and the BRIC 40 Index, it reasonably experiences a completely different pattern with mean and standard deviations that are considerably higher. Finally, the commodity index, the S&P GSCI, results to be the more volatile, with an annualized standard deviation of 17.65%.

Figure 1 underneath displays the efficient frontier of risky assets as well as the single asset allocations in the expected returns-standard deviation plane. The 3-Months Treasury Bill Rate was chosen as the risk-free rate implied for the portfolio's computations.

Figure 1. **Efficient Frontier of Risky Assets**



Results from the unconstrained optimization problem suggest that the Global Green Bond Index is a component of the optimal portfolio whenever low levels of portfolio's annualized returns are considered. Despite the straightforward intuition that low levels of returns would prescribe a higher proportion of investments in the bonds' side, what is actually interesting is that the green index delivers higher diversification benefits with respect to its comparable Global Aggregate Bond Index. As a matter of fact, the latter does not belong to the optimal portfolio requiring a targeted return of either 2.5 or 3%. Hence, as the two indices belong to the bond category, it must be that the Global GBI is superior for some intrinsic characteristics it possesses. This conveys the idea that green assets' potential has been somewhat recognized in the market. For green assets have emerged in the past couple years, this result seems to cope with an initial modest approach undertaken by investors, who happen to be among the firsts investing in such type of security. Results which the above statements refer to are displayed in Table 2 and 3 below.

Table 2. **Asset Allocation for 3% Targeted Returns**

Target Return: 3% (Annualized)	
US AGGREGATE	81.95%
GLOBAL GREEN	4.83%
MSCI	12.70%
MSCI EM ASIA	0.52%
Annualized Stdv	**2.84%**

Table 3. **Asset Allocation for 2.5% Targeted Returns**

Target Return: 2.5% (Annualized)	
US AGGREGATE	83.55%
GLOBAL GREEN	9.13%
MSCI	5.77%
MSCI EM ASIA	1.00%
S&P GSCI	0.55%
Annualized Stdv	**2.70%**

Contrarily, if higher levels of returns are required, the Global Green Bond index does not appear to be one of the possible investment choices. Indeed, investors whose degree of risk aversion is lower, and who are thus more willing to undertake risks, do not retrieve any benefit from the consideration of the Global GBI. Presumably, the reason is related to the fact that selecting the US Aggregate Bond Index, which is endowed with lower risk with respect to the Global GBI, would allow investor to allocate a greater amount of wealth onto the MSCI World Index compared to the amount it would receive if the instead the asset allocation would be constituted by just the MSCI Index and the Global GBI. As a matter of fact, the latter would be also associated with a higher portfolio's risk.

The second mean-variance analysis, also referred to as the constrained one, aims at comparing the asset allocation choices and the portfolio's risks and returns characteristics, when the difference comes from the type of investor considered. The way in which their decisions differ depends on the parameter ϑ, which is conceived as the one reflecting green preferences. The way in which these preferences have been assessed in the thesis consists of inequality constraints introduced in the optimization problem. The first assumption concerned the distinction between two types of green investors, a *moderate green* one, who was assumed to require at least a 5% of wealth allocated to the Global GBI, and a *high green* investor requiring instead a 10% investment in the Global Green Bond Index. An explanation for why such values have been chosen is coherent with the fact that we are still experiencing a transition phase towards a greener economy and greener financial world, which implies that the proportion of wealth allocated into the Global GBI could not embody extremely high values. Briefly summarising the findings of the previous analysis, low targets of expected returns already imply some investments in the Global GBI, whilst higher amounts of target returns, which in the previous analysis were assessed at 5 and 7% (annualized), did not result in allocations which entailed green bonds. Hence, the constrained optimization analysis here presented aims at understanding what would be the portfolios' outcomes for green investors requiring substantial amount of expected returns.

The first asset allocation that is analysed, and which is exposed in Table 3 below, is the one referring to an optimal portfolio requiring 5% expected returns.

Table 3. **Asset Allocation for 5% Target Returns Portfolio**

Target Return 5%			
Moderate Green		***High Green***	
US AGGREGATE	47.69%	US AGGREGATE	42.39%
GLOBAL GREEN	5.01%	GLOBAL GREEN	10%
MSCI	47.30%	MSCI	47.61%
Annualized Stdv	**4.99%**	**Annualized Stdv**	**5.06%**

The first thing worth noting when considering the asset allocation for a moderate and a high green investors' portfolio with 5% Target Return is that the changes applied to the portfolio's allocations occur at the expenses of the US Aggregate Bond Index, which indeed decreases from a value of 53% to approximately 48% and 43% in the case of a moderate and a high-green investor, respectively.

Yet, this could be expected as the requirement of moderately high expected returns suggests a significant part of wealth be allocated to the MSCI World Index.Another consequence stemming from the consideration of green constraints is that the overall risk of the portfolio slightly increases. Indeed, the annualized risk for a brown portfolio of 5% returns, not endowed with any constraint was 4.91%. In the optimal portfolios incorporating the Global GBI the standard deviation is slightly higher, 4.99% and 5.06% for a moderate and high green investor respectively, even though the difference is presumably negligible as it is justified by the investors' willingness to hold the specific green asset. Furthermore, the changes in the optimal allocations and the results on the annualized risk of the optimal portfolios associated to a 7% target return are coherent with those of the Target 5% Portfolio.

The final analysis concerned the Sharpe ratios resulting from the 5 and 7% Target Portfolios of both the unconstrained and the constrained cases. What seems to emerge by the two analysis is that "*going green"* occurs at a cost, in terms of lower Sharpe Ratios. This is line with previously conducted studies suggesting that ethical investments are usually associated to lower Sharpe ratios with respect to their conventional counterpart. None the less, it is interesting to look at the problem from another perspective, which is in line with the aim of thesis. The difference in Sharpe ratios could indeed reflect the value a green investor assigns to the green investment itself. Thus, if for a conventional mean-variance preferences' investor the difference is perceived as a cost, it could correspond exactly to the specific value-added brought by green bonds that is retrieved in the form of a higher utility by the green investor. First of all, the Sharpe Ratios resulting from the unconstrained optimization problem in the case of 5 and 7% targeted returns are, respectively:

$$S_{5\%} = \frac{0.05 - 0.0312}{0.0491} = 0.382 \qquad S_{7\%} = \frac{0.05 - 0.0312}{0.080} = 0.485$$

Additionally, the Sharpe Ratios for either levels of required returns were assessed for both the moderate and high green investor. Thus, the Sharpe Ratios for portfolio's entailing 5% returns are

$$Moderate\ Green\colon\ S_{5\%} = 0.377$$
$$High\ Green\colon\ S_{5\%} = 0.371$$

while those for the 7% target return portfolio are

$$Moderate\ Green\colon\ S_{7\%} = 0.480$$
$$High\ Green\colon\ S_{7\%} = 0.474$$

Hence, we see that, in this specific context, a moderate green investor presumably has a parameter ϑ of 0.005, a sort of ethical-green return which is not embodied in the financial one. Moreover, the value of ϑ for a high green investor is reasonably higher and, in the specific context here analysed, results to be equal to 0.011.

Conclusions

The considerable importance that climate change has achieved in the latest years has been mirrored by the extremely rapid growth that has characterized the green bond market since its first appearance in the financial world. This market has seen the development of specific financial products, green bonds, issued with the aim of providing solutions to threats and issues posed on the environment by climate changes.

The mean-variance analyses performed in the study attempts at understanding whether green bonds are likely to be included in a portfolio, first evaluating a choice for a mean-variance preferences' investor, and then by considering the outcomes for green investors. Results from an initial statistical analysis seems to suggest that, among the three green bond indices initially selected, the one that would most likely be considered by a conventional brown investor is the Bloomberg Barclays Global Green Bond Index. As a matter of fact, the latter is the green bond index that has been characterized by the higher annualized mean for the period considered in this study. What has emerged from the unconstrained analysis is that green bonds would be a good investment choice for investors requiring low levels of returns. Contrarily, for standard mean-variance preferences' investors inclusion of green assets in the portfolio does not deliver any additional benefit, thus the latter does not appear as investment choice constituting the optimal portfolio. Nevertheless, it is relevant to underline that the investor considered in this first part of the analysis is someone for which holding some green assets does not convey additional utility values. Thus, it seems reasonable to believe that the situation for investors who value the greenness of a portfolio could deliver better results with respect to the ones achieved here. Results from the constrained optimization problem seem to suggest that investors who have green preferences undertake a slightly higher risk when requiring portfolios with moderate amount of expected returns endowed with green securities. None the less, the slight increase realizes as a consequence of delivering more weights to the green assets, thus highlighting the fact that green investors are presumably aware and willing to take on this little additional risk to have green features in the portfolios they hold.

Moreover, the Sharpe ratios associated to those portfolios are lower with respect to those emerging from optimal portfolios of assumed brown investors. Nevertheless, this is line with previously conducted studies suggesting that ethical investments are usually associated to lower Sharpe ratios with respect to their conventional counterpart.

All things considered, the analysis here conducted does not seem to deliver strong results which are able to fully justify the growing interest for the green bond market. Moreover, for the negligible, but slightly positive results found in this study, it may be that it is too early to be able to perceive the benefits associated to green bonds inclusion into portfolio selection. Nevertheless, green bonds are a newly developed tool, which, in line with the increasing regulation and growth of the green market, will probably become an important tool in the future financial scene.