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"Integrating ESG Performance in Portfolio Optimisation: evidence from European market"

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Firma (signature) Alessandro Pinamonti ……………………………………..

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Introduction

Portfolio allocation has always played a key role in the world of finance. Investors aim to increase their wealth generating abnormal returns by adopting different asset allocation strategies in line with their preferences. Traditionally, portfolio allocation has been driven by historical assets' financial performance as the main indicator of future portfolio's performance.

However, portfolio allocation strategies have experienced radical transformation over the past few years. Institutional and traditional investors no longer focus exclusively on factors related to the financial performance of their investments, but are also interested in environmental, social and governance dynamics. In recent years, the investors' demand for ESG asset dramatically increased. The growing demand for sustainable assets arises from an increased awareness of issues such as climate change, protection of minorities and management fraud or anti-corruption systems. A measure of ESG profile has been developed by the leading rating agencies, which assign an ESG score to companies in order to assess their performance on these non-financial criteria. The ESG scores are an indicator of corporate social responsibility, i.e. how each company deals with the environmental, social and governance issues. Recently, ESG performance has become the new criterion for asset valuation and selection.

According to a global survey conducted by Amel-Zadeh and Serafeim (2018), ESG information are mainly employed by investors as an investment performance indicator. Some studies support that being socially responsible increases investment financial performance: Statman and Glushkov (2009) demonstrated in their research that socially responsible portfolios can perform better than traditional portfolios, confirming the "doing good while doing well" hypothesis. However, some other studies support the opposite argument. Geczy et al. (2005) highlighted the cost of imposing an SRI constraint in portfolio allocations. It is possible to observe that the literature does not provide a clear consensus on Socially Responsible Investing (SRI).

In this study, we propose to examine the effect of integrating ESG performance into the asset selection and portfolio allocation. By applying an extension to the Markowitz model which includes the introduction of the ESG score as a third portfolio evaluation criterion, we aim to measure the differences in financial performance between traditional and ESG allocation strategies. The analysis is based on a sample of companies which are included in the Stoxx Europe 600 index.

The document is divided into 4 chapters.

In Chapter 1 we provided a general overview of Socially Responsible Investing. We focused on describing the evolution of sustainable investments in recent years in the five major regions of the world. We identified seven different types of ESG strategies by describing and ordering the strategies preferred by investors without disregarding the limitations of ESG information and the risks associated with them. We investigated the topic on sustainable investments at the European level indicating the major funding provided and regulations implemented by the European Union and other European states in order to identify the main drivers for sustainable investments in the future.

In Chapter 2 we conducted a review of traditional and more recent literature. We described the Modern Portfolio Theory developed by Harry Markowitz, who considers exclusively two criteria in evaluating the financial performance of an asset: return and risk. We analysed and reported the main results of the studies that introduced ESG performance into asset selection and allocation, favouring research that extended Markowitz's model adding ESG score as third criterion.

In Chapter 3 we performed an empirical analysis of the European stock market employing companies included in the Stoxx Europe 600 index. The analysis aimed to compare the historical financial and non-financial performance between traditional Markowitz allocation strategies and sustainable strategies. The realized sustainable strategies extend the Markowitz model by integrating ESG score as a third factor for asset selection and allocation. The analysis was firstly conducted on a sample of companies utilizing the most recent data available and subsequently on other samples of companies utilizing past data.

In Chapter 4, we performed a backtest on the allocation strategies in order to assess their effectiveness in predicting future performance. We compared the in-sample and out-of-sample periods of the different samples of companies by calculating the average returns, standard deviation, ESG portfolio scores, the Sharpe ratio, and the delta ratio. Moreover, we implemented an out-of-sample portfolio based on a 5-year rolling window approach with annual rebalancing from 2011 to 2021 and we computed the cumulative returns to examine the trend between conventional and sustainable portfolios.

Chapter 1

Socially Responsible Investing - Background setting

The growing awareness of the widespread impacts of climate change and other emerging threats such as aging populations, data and privacy concerns, and mass migration increased traditional investors' interest in the identification and management of potential climate and social risks. Given the high frequency and costs of extreme climate events, investors have become increasingly concerned about the impact of these issues on assets and financial statements. These issues are likely to have a significant effect on investment performances metrics. However, traditional risk and analysis models failed to adequately capture them. Moreover, in recent years, there has been a rise of regulatory initiatives which prompted large institutional investors to apply strategies and analyses that takes into consideration environmental, social and governance (ESG) issues into their investment approaches. This emerging wave of interest in the so-called green finance and the increasingly rigorous regulatory system which large institutions are implementing, are directing financial flows towards environmentally and socially sustainable investment projects. In this context, a growing number of investors is convinced that is no longer allowed to ignore ESG criteria in the choice of securities to be included in portfolios. Therefore, as these risks and their potential impacts increase, so raises the investor interest in incorporating ESG considerations into financial models to identify and mitigate these risks.

Socially responsible investing (SRI), as reported in some research such as the study of Shank et al. (2005) and the paper of Statman (2006), means “integrating personal values and societal concerns with investment decisions”. In more recent times, it refers to any investment strategy that, in addition to conventional financial performance, also incorporates consideration of environmental, social, and governance (ESG) criteria. Eurosif (2018) defined SRI as “a long-term oriented investment approach which integrates ESG factors in the research, analysis and selection process of securities within an investment portfolio”. With this type of investment strategy investors want to direct their investment choices towards businesses that are sensitive to certain environmental, social and governance parameters and not simply considering financial performance metrics. As a result, investors are willing to sacrifice a portion of their financial returns in favour of investing in assets that improve social and environmental quality and are in line with their values and goals.

As published by Schueth (2003) in his research, the modern concept of socially responsible investing has its historical origins in the United States during the 1960s. In that period people were fighting for important issues such as the movement against the war in Vietnam and the Cold War, race and gender equality, and equal rights. These movements were the principal drivers which have partially contributed to a shift in investment focus toward greater social and cultural inclusion. In the 1980s incidents involving a strong media impact such as the Bhopal environmental disaster, the explosion of the Chernobyl nuclear power plant and the Exxon Valdez oil tanker accident in the waters off the coast of Alaska contributed to increase the environmental concern of people. Investors began to take an interest in environmental issues and to developing investment strategies which exclude from the investment universe assets tied to dangerous environmental and social impacts, such as businesses of weapons or nuclear power generation companies. In more recent times, socially responsible investments have embraced issues related to human rights and poor occupational health and safety conditions. To date, the available data shows that SRI has experienced explosive growth worldwide: more and more retail and institutional investors are relocating their financial flows towards "green" assets.

1.1 SRI worldwide

In recent years, sustainable investments have grown at a rapid pace worldwide because of a greater sensibility towards sustainability and more regulation, incentives, and sustainable initiatives put in place by national and supranational institutions.

The report Global Sustainable Investment Review 2020, produced by the Global Sustainable Investment Alliance (2021) shows that in 2020, a total of $35.3 trillion was invested in sustainable assets in the top 5 investor regions (Europe, the United States, Canada, Japan, and Australasia), 15% more than in 2018 and 54.5% more than in 2016. As can be seen in the Figure 1, in 2020 the United States is the country with the largest absolute amount of investment in sustainable assets with about $17 trillion overcoming Europe in which investors placed roughly $12 trillion. Collectively, the United States and Europe, constitute more than 80% of global investments in sustainable assets. It is worth mentioning that even though Europe is one of the regions where the largest number of investments in sustainable assets are executed, the data shows a 12,8% decrease of the socially responsible investments in 2020 compared to 2018. The decrease in investments in sustainable assets in Europe may be explained by the recent implementation of stricter a regulation regarding the classification of what assets shall be considered sustainable.

The Global Sustainable Investment Alliance reported also that Canada is the country which has proven to be the market with the highest incidence of ESG investments on the total investments. In 2020 with a rate of 62% it is the leading country for ESG investments with respect to the local total assets under management. In facts, data in the Figure 1 show that Canada has the highest growth rate of sustainable investments between 2018 and 2020: 48%.

ESG investments data related to the region of Australasia show that investments in sustainable assets have experienced steady increase. During the period 2018-2020, growth has slowed down due to a regulatory redefinition of what is qualified as a sustainable asset.

Japan is the country that overall has experienced the largest increase in investment in sustainable assets over the recent years. Indeed, with approximately $3 trillion[1] invested in green assets in 2020, it had the highest growth rate among global countries since 2014.

Figure 1: Regional sustainable investments in local currencies[2]

	2014	2016	2018	2020	GROWTH PER PERIOD GROWTH 2014-2016	GROWTH 2016-2018	GROWTH 2018-2020	COMPOUND ANNUAL GROWTH RATE (CARG) 2014-2020
Europe (EUR)	€9,885	€11,045	€12,306	€10,730	12%	11%	-13%	1%
United States (USD)	$6,572	$8,723	$11,995	$17,081	33%	38%	42%	17%
Canada (CAD)	$1,011	$1,505	$2,132	$3,166	49%	42%	48%	21%
Australasia (AUD)	$203	$707	$1,033	$1,295	248%	46%	25%	36%
Japan (JPY)	¥840	¥57,056	¥231,952	¥310,039	6,692%	307%	34%	168%

Source: Global Sustainable Investment Alliance

To sum up, these data suggest an increasing interest and focus on assets that include also environmental, social and governance factors. The growth in the interest in sustainable assets is in line with the overall trend of the total global assets under management which in 2020 grew by 7.17% compared to 2018 and by and 20% compared to 2016, reaching over $98 trillion according to Global Sustainable Investment Alliance data. More interestingly, sustainable investments have an increasing incidence on total assets under management accounting for 27.9% in 2016, 33.4% in 2018 and 35.9% in 2020.

[1] The calculation has been performed by multiplying 310,039 yen in Figure 1 by the USD/JPY exchange rate at 31/12/2020.

[2] Asset values are expressed in billions.

1.2 Sustainable strategies

There are several types of strategies that investors can adopt when investing in ESG assets. For the sake of providing global visibility and clarity to sustainable forms of investment, the international organization Global Sustainable Investment Alliance (2021) identified seven types of investment strategies:

- Impact investing and community investing;
- Best in class/positive screening;
- Sustainability themed/thematic investing;
- Norms-based screening;
- Corporate engagement & shareholder action;
- Negative/Exclusionary screening;
- ESG integration.

The Figure 2 illustrates the amount of US dollars globally invested over the recent years through the above-mentioned investments strategies.

The **impact investing and community investing** strategy allows investors to finance funds, projects, or companies whose activities have a measurable positive environmental, social and governance impact, while realizing a financial return. This category includes community investments directed to traditionally under-resourced individuals or communities and to businesses with a clear social or environmental purpose. Numerically, it is the sustainable strategy with the historical lowest amount of money invested: $352 billion in 2020.

The **best in class/positive screening** strategy is an approach which aims at selecting companies or sectors with positive characteristics in terms of environmental, social and governance criteria and with determined high levels of rating.

The **sustainability themed/thematic investing** is a strategy used in the investment of specific asset classes that provide sustainable solutions and, therefore, it is directly related to environmental and/or social development.

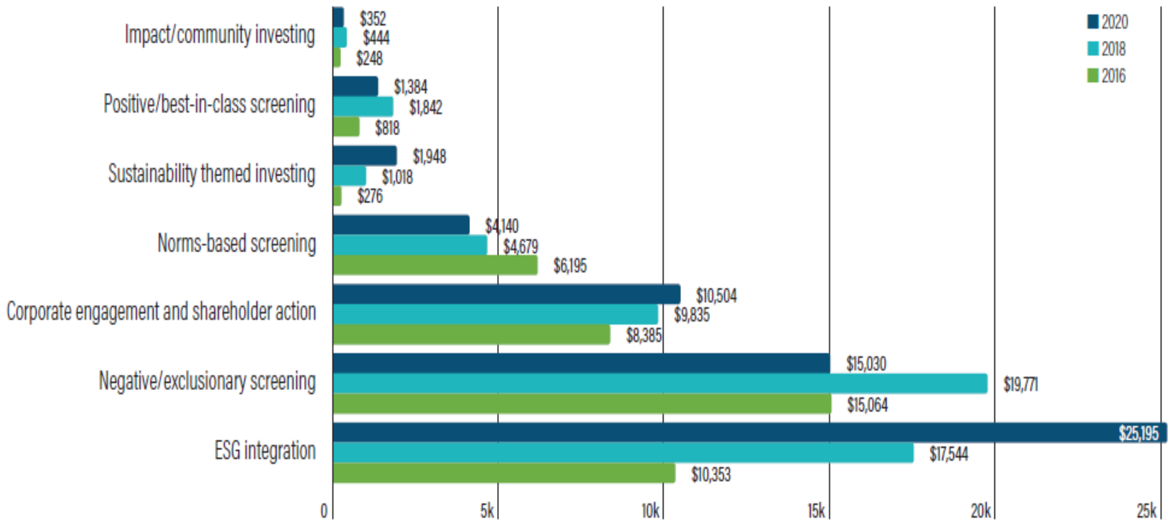
The **norms-based screening** is a sustainable investment strategy focused on investment decisions depending on their compliance with international norms and standards regarding ESG factors. The norms and standards are issued by international organization such as United Nations (UN), the Organization for Economic Co-operation and Development (OECD) or International Labour Organization (ILO).

The **corporate engagement & shareholder action** is a strategy that involves the active engagement of investors. It exploits shareholder authority in order to influence the decision-making behaviour of the companies in which they have invested towards initiatives that comply with environmental, social and governance parameters.

The **negative/exclusionary screening** strategy consists of excluding from the investment portfolio specific companies, industries or countries that are in conflict with issues related to climate risk, values, or social rules such as companies involved in tobacco, alcohol, nuclear energy and weapons.

The **ESG integration** is the most widespread sustainable investment strategy which consist of the consideration by the investors of ESG factors during the financial analysis and investment choices. Between 2016 and 2020 this investment strategy grew more than 140% reaching in 2020 a total investment of more than $25 trillion.

Figure 2: Sustainable investment strategies[3]



Source: Global Sustainable Investment Alliance (2020)

As shown in Figure 2, investors prefer to allocate their wealth on lighter ESG strategies, such as the negative screening strategy and ESG integration strategy. Most popular ESG strategies do not have as their primary objective the generation of a positive social and environmental impact. On the other hand, strategies that pursue a more ESG impact-oriented goal are impact investing and sustainability themed investing, approaches where much less wealth has been invested.

[3] Asset values are expressed in billions of US dollars.

1.3 Limitations and transparency of ESG information

The historical limitation on Socially Responsible Investing has been the absence of ESG data on which to begin the investment analysis. While companies report financial performance every quarter, information on their environmental impact, labour relations, social impact, and governance structures has always been limited, lacking in transparency and difficult to identify.

Nowadays, however, many providers, such as MSCI, Bloomberg, S&P, Thomson Reuters, and others, offer detailed and complete ESG information for thousands of companies, and, at the same time, more and more corporations are regularly producing extensive reports on their ESG performance and ESG risks. The ongoing database creation and standardization of ESG data allows for an easier and increasing availability of data that helps investors to get a better understanding of ESG ratings in order to perform sustainability analyses into their investment choices.

However, it is necessary to be cautious for investors wishing to make sustainable investments, as companies might circumvent the rules for disclosure of non-financial information related to ESG criteria. In particular, focusing on the environmental matters, in the recent past some companies stood out to have launched a marketing campaign to raise awareness of environmental sustainability. The campaign turned out to be a way to improve the image of the company to the public in order to attract green investors and divert attention from the real core business. This growing phenomenon whose aim is not really to be environmental compliant but instead to gain access to a larger share of possible investors, is known as **greenwashing**. Delmas and Burbano (2011) defined the greenwashing as "the act of misleading consumers regarding the environmental practices of a company (firm-level greenwashing) or the environmental benefits of a product or service (product-level greenwashing)".

A clear example of greenwashing may be defined by the 2015 Volkswagen case: the German car manufacturer, during tests to monitor CO2 emissions, used a particular software that allowed cars to significantly reduce gas emissions with the intention of bypass the imposed emission standards. As it is quoted in the article by Schiermeier (2015), the application of the software enabled the falsification of real data gas emission. This has allowed the company to considerably accelerate the sale of its vehicles and increase revenues; later the US Environmental Protection Agency (EPA) discovered that the emissions of the machines were clearly above the values expressed during the tests.

The Volkswagen case is intended to highlight that the investors interested in certain environmental performances should not be simply deceived by messages and advertisements which communicate a positive environmental impact. Investors should consider the Corporate Social Responsibility companies reports for information regarding their environmental positioning. Typically, a considerable risk of greenwashing is associated with companies with weak environmental performance that, in contrast, communicate a positive message about their focus on environmental sustainability.

1.4 Investments drivers and regulations: the European framework

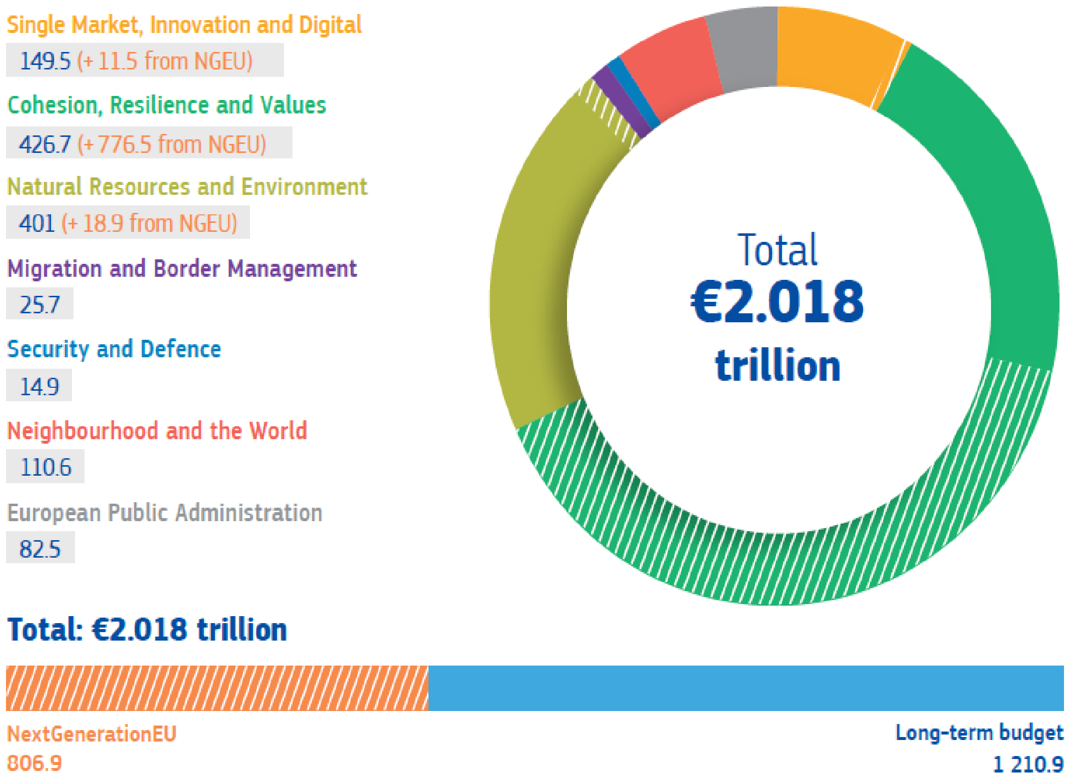
In 2015, the United Nations Assembly endorsed the 2030 Agenda for Sustainable Development, a global policy oriented to promote the transition to a low-carbon, more environmentally sustainable and resource-efficient global economy. In line with this objective, the Paris Agreement was signed in 2016 by the major world governments to significantly address the adverse impact of climate change and keep the average temperature increase to 1.5 C° above pre-industrial levels. The agreement also aims at facilitating the reallocation of financial flows towards strategies that improve the environmental sustainability and considerably reduce greenhouse gas emissions.

The European Commission (2018) announced its Action Plan on Financing Sustainable Growth. The Action Plan on Sustainable Finance has as main goals the reorganization of financial flows towards long-term investments which focus on the achievement of sustainable and socially inclusive development, the management of financial risks arising from climate change, environmental degradation, and social issues, and the promotion of transparency, stability, and persistence in financial and economic activity.

As a result of this challenging plan, the European Green Deal was stipulated in 2019. The member states of the European Union agreed upon the establishment of three main pillars: the reduction of carbon dioxide emissions by at least 55% by 2030 with respect to 1990 levels and to achieve zero greenhouse gas emissions by 2050, the decoupling of European economic development from resource allocation, and the inclusion of all sorts of people and respect of places. The European Commission (2020) has declared that over the next 10 years at least €1 trillion is expected to be moved into sustainable investments with a particular focus on climate and environmental issues. The Green Deal aims at simplifying the entry process to sustainable investments for public and private investors and to create a framework able to provide support to public administrations to organize and implement sustainable projects.

The recent global pandemic has laid down the foundation for implementing structural reforms across Europe and leading the continent towards a more inclusive, sustainable, and digitalized economy. Following the approval of the Multiannual Financial Framework (MFF), Europe's long-term budget, the European Commission (2021) disclosed the investment plan for the next seven years 2021-2027 which involves EUR 1210.9 billion. Together with the NextGenerationEU (NGEU) program - the stimulus package of nearly EUR 800 billion funded by the European Union for the revitalization and recovery of the economy from the coronavirus pandemic - the funds available to the member countries of the European Union exceed EUR 2000 billion.

Figure 3: MFF and NextGenerationEU investment plan 2021-2027



Source: European Commission

Approximately 30% of this program will be dedicated to financing the implementation of the European Green Deal with the aim of supporting projects focused on creating new renewable energy and circular economy businesses and new jobs without race or gender disparities. The program also plans to fund projects of companies that have a positive social and environmental impact, such as renovation of facilities and buildings or sustainable transportation, which can ensure the transition to a green economy.

As reported in the Figure 3, EUR 419.9 billion (EUR 401 billion from the MFF program and 18.9 from NGEU package) are going to be invested in natural resources and environment projects. These funds will be employed to guarantee to the EU member states a financial support in the sector of agriculture, fishery, and aquaculture to achieve climate neutrality and a more efficient use of natural resources guaranteeing sustenance to the countries most affected by the transition towards a more sustainable economy.
Nearly EUR 1.2 trillion (EUR 426.7 from MFF program and 776.5 from NGEU package) will be spent in order to strengthen cohesion among member countries and reduce social inequality, finance social and inclusive projects and support the negative economic and social impact generated by the coronavirus pandemic.

For the purpose of ensuring a single guideline in sustainable investment topics, the European Parliament adopted the Sustainable Finance Disclosure Regulation (SFDR) in 2019. The SFDR[4] is a new framework that defines and clarifies sustainable investment with the goal of facilitating for investors to understand ESG valuation metrics and it imposes compulsory ESG disclosure requirements on asset managers and other financial market participants.

The Sustainable Finance Disclosure Regulation provides a precise definition of sustainable investment. According to article 2 in Sustainability-related disclosures in the financial services sector (Regulation 2019/2088) "an investment is considered sustainable when it contributes positively to achieving a certain environmental objective concerning energy use, the use of renewable energy, the use of raw materials and water resources and the use of land, waste production, greenhouse gas emissions as well as the impact on biodiversity and the circular economy, or an investment in an economic activity that contributes to a social objective, in particular an investment that contributes to the fight against inequality, or that promotes social cohesion, social integration and industrial relations, or an investment in human capital or economically or socially disadvantaged communities provided that such investments do not significantly harm any of these objectives and that the companies benefiting from such investments comply with good governance practices".

As a result of these new policies and regulations, the EU Taxonomy was issued in 2020 with the aim of creating a common framework for the classification of sustainable investments. In the EU Taxonomy the establishment of a framework to facilitate sustainable investment, and

[4] The Sustainable Finance Disclosure Regulation (SFDR) is applicable since March 2021.

amending Regulation (EU) 2019/2088 (Regulation 2020/852) six environmental objectives[5] were set:

1. Climate change mitigation;
2. Climate change adaptation;
3. The sustainable use and protection of water and marine resources;
4. The transition to a circular economy;
5. Pollution prevention and control;
6. The protection and restoration of biodiversity and ecosystems.

To reinforce the regulatory framework on ESG investments developed by the European Union the so-called Corporate Sustainability Reporting Directive (CSRD) has been recently proposed. This directive will require large listed and unlisted companies, as well as small and medium-sized listed companies, to publish clear and transparent information regarding economic activities related to environmental, social and governance criteria.
Furthermore, in order to increase awareness and demand for ESG assets the European Commission has proposed to introduce in Markets in Financial Instruments Directive II (Mifid II) the requirement for financial intermediaries to ask investors for sustainability preferences with the aim of raising investor appetite for sustainable financial products.
This system of proposals and regulations (still being defined) aims at developing a uniform framework among the member states of the European Union with the ultimate long-term goal of achieving an environmentally sustainable, inclusive, and modern Europe.

European countries outside the European Union are also adapting their sustainable finance regulations to comply with the Paris Agreement.
Norway, despite not being part of the European Union, has adopted the regulatory sustainability risk disclosure requirements imposed by the SFDR and the EU taxonomy.
The United Kingdom has not adopted EU regulations such as SFDR or the EU taxonomy. However, the UK it is currently working its own regulatory framework on sustainable finance. The Financial Conduct Authority (2021) reports on the Sustainability Disclosure Requirements (SDR), a regulation that requires companies to disclose non-financial information related to sustainability, identifying opportunities and impacts. In addition, a labelling system for financial products was proposed in order to categorize their sustainability

[5] As reported by European Commission, the EU taxonomy disclosure requirements came into force in January 2022 and covers the first two climate targets (climate change mitigation and climate change adaptation), the remaining four targets will be defined in new acts which are going to be applicable from January 2023.

and to foster green finance, to help investors have greater transparency about sustainable financial products, and to create a reliable and transparent ESG marketplace.
In Switzerland, the Swiss Financial Market Supervisory Authority FINMA is working on the disclosure requirements by large banks and insurance companies regarding climate-related financial risks, following the guidelines suggested by the Task Force on Climate-related Financial Disclosures (TCFD) and trying to effectively counteract greenwashing.

Overall, in line with the study performed by Eurosif (2018), socially responsible investments in Europe are mainly allocated between equities and bonds. The market drivers that will mostly push investments in this field will be the increased demand for sustainable assets from institutional and retail investors. Investors are steered towards this type of assets by the continuous evolution and updating of European legislation and international initiatives which aim to facilitate and promote environmentally, socially and governance sensitive projects.

Chapter 2

Literature review

Nowadays, more investors are not exclusively interested in the return on their assets. Investors have become concerned with assets that contribute to more sustainable environmental and social development. In particular, retail and institutional investors demand for assets that positively contribute to the impact of carbon dioxide emissions on the environment and thus reduce global warming and the resulting problems.

Up to now, selection criteria and portfolio optimisation models were based solely on traditional financial performance, which did not consider the negative externalities that assets might produce. Now, investors are no more willing to ignore ESG performance as a criterion for asset allocation.

For this purpose, the recent literature shows an increasing number of studies converging towards new models of asset selection and portfolio optimisation that take into account social and environmental impact in addition to traditional financial metrics such as risk and return.

We divided the literature review in two parts. Firstly, we described the model of Markowitz focusing on strategies traditionally applied in portfolio optimisation. Subsequently, we summarize the papers which deal with socially responsible portfolio allocations. Generally, the sustainable strategies described are extensions of the model of Markowitz which consider the ESG information as a criterion.

2.1 Markowitz model

Harry Markowitz is the pioneer of strategy development for portfolio selection. In his study "Portfolio Selection", Markowitz (1952) suggested that the selection of an optimal portfolio starts with the observation and experience of an available universe of securities to predict future performances and it concludes with the allocation of wealth to be invested in the identified assets.

In a following research, Markowitz (1959) developed an innovative portfolio theory also known as the Modern Portfolio Theory that granted him the Nobel Prize for economy in 1990. The Modern Portfolio Theory represented the starting point for the implementation of new portfolio theories and even today it is a significant source of inspiration for the development of further portfolio selection models.

As Markowitz suggests, portfolio selection depends on two different parameters: risk and return. The main idea behind his theory is that all investor wants to maximise the portfolio return by minimising its risk. Introducing the concept of correlation among securities, Markowitz stated that the risk of a portfolio can be reduced by diversifying the portfolio. The correlation may be positive if securities move in the same direction, negative if they move in the opposite direction. As explain by Rosenberg and McKibben (1973), the total risk of an asset can be split into two components: the systematic risk or market risk, which can be associated with all assets without exception, and the non-systematic risk or specific risk, which can be associated with a single security. Considering the correlations, the portfolio diversification reduces risk without affecting performance by eliminating the specific risk of each security in the portfolio.

According to this theory, there are several optimal *mean-variance* portfolios that lie on a concave curve, also called *efficient frontier*. In this frontier to each return level corresponds a determined level of risk. The *efficient frontier* is the set of optimal portfolios that express the best result in terms of risk and return. Each investor should choose a single portfolio on the efficient frontier that is in line with his own risk profile.

The main assumptions of the Modern Portfolio Theory are:

- investors are considered rational and risk-averse;
- the market has perfect competition, and it is exempt from information asymmetry;
- transaction costs and taxes are negligible;
- investors have unlimited access to wealth to invest being able to borrow money at a risk-free interest rate;
- the returns of the securities follow a normal distribution; therefore, the expected return is the return with the greatest probability of occurring in the future;
- all market participants have a single period as a time horizon.

In the model settled by Markowitz, the future beliefs associated with the return of a specific security are expressed by the expected return $E(\mu)$, while the future beliefs associated with the risk of a security are represented by the standard deviation σ of the returns. The literature shows that there are several methods for calculating the expected return and risk such as sample estimation, equilibrium smoothing methods or other models such as the Capital Asset Pricing Model (CAPM) and Arbitrage Pricing Theory (APT).

Despite believing there were better prediction methods, Markowitz suggested basing his analysis on the future performance of the assets to be considered in the portfolio from a sample estimation of past historical performance.

Considering N risky assets in a determined investable universe, for each asset i, with $i = 1, 2, \dots, N$, we have:

- an expected return $\mu_i = (\mu_1, \mu_2, \dots, \mu_N)$;
- a variance $\sigma_i^2 = (\sigma_1^2, \sigma_2^2, \dots, \sigma_N^2)$.

An investor with a fixed amount of wealth w can invest a specific portion of wealth w_i in each risky asset i with the purpose of constructing the portfolio P.

The expected return of the portfolio $E(\mu_P)$ is given by the formula $E(\mu_P) = \omega^T \mu$, where ω is a column vector which represents the weights associated to each risky asset i and it is given by the formula $\omega_i = \frac{w_i}{\sum_{i=1}^{N} w_i}$, with $\omega \epsilon \mathbb{R}^N$. $\omega^T = (\omega_1, \omega_2, \dots, \omega_N)$ represents the $1 \times N$ transpose vector of the column vector ω, and μ exemplifies the $N \times 1$ column vector of the expected returns of the N risky assets. The variance of the portfolio P is defined by the formula $Var_P(\omega^T \mu) = \omega^T \Sigma \omega$, where Σ symbolizes the $N \times N$ variance-covariance matrix composed by variances of the risky asset i in the diagonal of the matrix and by the covariance $\sigma_{i,j}$ determined by the risky asset i and the risky asset j. So, the variance-covariance matrix is defined:

$$\Sigma = \begin{bmatrix} \sigma_{1,1} & \cdots & \sigma_{1,N} \\ \vdots & \ddots & \vdots \\ \sigma_{N,1} & \cdots & \sigma_{N,N} \end{bmatrix} = \begin{bmatrix} \sigma_1^2 & \cdots & \sigma_1 \sigma_N \rho_{1,N} \\ \vdots & \ddots & \vdots \\ \sigma_N \sigma_1 \rho_{N,1} & \cdots & \sigma_N^2 \end{bmatrix}$$

where $\sigma_{i,j} = \sigma_i \sigma_j \rho_{i,j}$ signifies the covariance between the risky asset i and the risky asset j, for each i and $j = 1, 2, \dots, N$, and $\rho_{i,j}$ represents the correlation between the risky asset i and the risky asset j.

According to Markowitz, several methods exist to identify as many different optimal portfolios. The *Global Minimum Variance* (GMV) is the portfolio with the minimum attainable variance lying on the efficient frontier. With this category of portfolio, the investor is disinterested in the expected return of the portfolio. Mathematically, in order to build the GMV portfolio and to find the optimal weights related to each risky asset i, it is necessary to minimise the function of the variance:

$$\min_{\omega \epsilon \mathbb{R}^N} \omega^T \Sigma \omega,$$

subject to the constraint

$$\omega^T \mathbf{1} = 1,$$

where $\mathbf{1}$ is a $N \times 1$ column vector composed by ones. The constraint ensures that the sum of the weights associated with the different assets is equal to one and therefore that all the available wealth has been invested. The solution obtained solving the optimisation problem provides a column vector of optimal weights $\omega^* = \frac{\Sigma^{-1}\mathbf{1}}{\mathbf{1}^T\Sigma\mathbf{1}}$, where Σ^{-1} is the inverse matrix of the variance-covariance matrix.

Alternatively, when an investor seeks to reach a determined level of expected return r, it could be possible to add to the previous optimisation problem a constraint which is able to guarantee the portfolio a certain threshold return. In this situation, the mathematical representation of the problem is:

$$\min_{\omega \epsilon \mathbb{R}^N} \omega^T \Sigma \omega,$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \mu = r.$$

Solving the optimisation problem with the newly added constraint, assuming that the return r is reachable, provides the solution to find the optimal portion of wealth to invest in asset i such that the portfolio has the minimum allowable variance and a return equal to r.

Conversely, it is possible to arrange the optimisation problem focusing on the expected return of a portfolio. However, solving the optimisation problem by simply maximising the return function $\omega^T \mu$ could lead to extreme weights and significantly risky solutions. Even avoiding the short selling, the optimisation problem would provide an optimal solution in which the total wealth would be invested in the single asset with the highest expected return. With this method, the investor would be assuming a considerable risk deriving from the systematic risk incorporated in that specific asset. A risk that could be diminished through assets diversification.

The optimisation problem that creates the *Maximum trade-off* portfolio allows to overcome this problem modifying the objective function to maximise. The mathematical visualization of the problem consists of:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \mu}{\sqrt{\omega^T \Sigma \omega}},$$

subject to the constraint

$$\omega^T \mathbf{1} = 1.$$

The objective function is determined by the ratio of the function that calculates the expected return of the portfolio to the function that calculates the standard deviation of the portfolio, i.e., the risk. The solution of the optimisation problem leads to a column vector ω^* which represents the optimal weights to pair to each asset i and maximises the trade-off between expected return and portfolio risk. The solution is given by $\omega^* = \frac{\Sigma^{-1}\mu}{\mathbf{1}^T\Sigma\mu}$.

Although the Modern Portfolio Theory has been considered a breakthrough and a theory to take inspiration from, the Mean-Variance model of portfolio optimisation developed by Markowitz has not been spared criticism from the literature. Indeed, the assumptions made by the author are far detached from reality: in the real world, it is impossible to ignore transaction costs and taxes, and investors cannot borrow unlimited capital at a favourable interest rate to invest in their portfolios; moreover, the returns associated with a specific asset are unlikely to follow a normal probability distribution.

In addition, the MV portfolio optimisation theory identified the risk of the assets with the standard deviation which overlooks deeper aspects of financial risk as it is merely a measure of distance from the expected return. Furthermore, estimation and time-consistency problems may arise; in fact, it is difficult to foresee correct and trustworthy estimates of the future performance of the different assets, as well as it is not certain that the efficient portfolio in which an investor invests capital in the present can also be considered efficient in the future.

Applying the Markowitz optimisation problem without any constraints, the most efficient solution could be illogical by concentrating a large amount of capital on a few individual securities and thus losing the portfolio diversification property. At the same time, efficient portfolios are considered unstable, in fact, as Michaud (1989) explains in his study, small variations in the expected returns or risks of the assets in a portfolio can lead to a significant change in the vector of optimal weights. The reason behind is that mean-variance optimisation requires a solution involving the inverse of the variance-covariance matrix, which could generate unstable results.

In the same paper Michaud criticizes the Markowitz model as being an "estimation-error maximiser" since the inputs provided to compute the optimal solution are calculated through sample estimation and the estimates are subject to error. The optimisation may overweight assets with high estimated return or low estimated risk and, conversely, underweight assets with low estimated return and high estimated risk, producing extreme weights. For this reason, in some cases, a simple equally weighted [6] portfolio may outperform a Mean-Variance optimised portfolio.

In order to understand the inaccuracy of the parameter's estimates used for portfolio optimisation, Jobson and Korkie (1980) tested with real data how far out of range the estimated variance-covariance portfolios were from the true efficient frontier. A sample of 20 randomly selected stocks with a 313-monthly return time series with data from 1949 to 1975 was utilized in their experiment. The conclusions of the experiment indicated that the optimal weights of the estimated efficient portfolios are noisy. In addition, the imprecision of estimations increases as the number of assets considered in the portfolio increases but decreases as the sample length of the time series on which the forecasts are based increases.

One solution that can counteract the irrationality of the extreme optimal weights consists in constrained optimisation. Placing new constraints on the objective function in such a way as to limit the distances between the optimal weights, thus imposing an upper and lower limit, can ensure an adequate portfolio diversification and an efficient solution.

Black and Litterman (1992) set out to improve the input estimates used by Markowitz in his optimisation model. The model proposed by the authors involves the integration of the investor sentiment about the future performance of the assets to be included into the portfolio construction process. The starting point for calculating the inputs to be considered in the optimisation process are the historical data to which the investor views are integrated. Investor views represent the expected excess return on assets, they are not considered absolute but follow a particular probability distribution: the higher the standard deviation of the views, the lower the confidence in the view and, therefore, the weight attributed. Hence, the efficient portfolio is created from inputs calculated by combining investor expectations and past performance. With this model, the estimates of the optimisation parameters are more efficient.

Despite some shortfalls in the model, with his theory Markowitz allowed each investor to process a large amount of data together and to create a portfolio that was in line with his objectives and his level of risk. As a result of Modern Portfolio Theory, it is possible to build a portfolio of assets that can achieve a certain return while at the same time being controlled in its exposure to risk.

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[6] An equally weighted portfolio is a portfolio (not considered efficient) composed by N assets to which equal weights $\omega_1 = \omega_2 = \cdots = \omega_N = \frac{1}{N}$ are associated.

2.2 ESG integration models

In the latest literature, a more effective and efficient asset allocation models have been developed. These models consider in processes of security selection and portfolio optimisation not only financial performance, but also other non-financial objectives targeted by investors, such as environmental, social and governance issues. In recent years numerous studies have attempted to compare traditional investment methods with methods that pay more attention to environmental and social sustainability. The most common thinking holds that socially responsible investment returns are lower than traditional investments; therefore, investors who also care about certain sustainability metrics will likely have to sacrifice a percentage of their financial return in order to meet those non-financial metrics. However, there is no consensus among researchers about the fact that sustainable investments, which meet some ESG criteria results, are less profitable than traditional ones. There are several studies which state that no empirical evidence has been found on the lower financial performance of socially responsible investments compared to other investments. For example, Capelle-Blancard and Monjon (2012) analysed the socially responsible investing literature from 1982 to 2009, stating that SRI literature had experienced rapid growth during that period. The literature has focused primarily on the financial performance of sustainable assets showing that this type of investment does not have a statistically significant impact in terms of return and risk compared to traditional investments. However, the authors state that the studies conducted on SRI and their results are mostly dependent on the data used in the analysis.

Subsequently, other studies confirmed the results of Capelle-Blancard and Monjon. Humprey and Tan (2014) in their research where compared a portfolio built with negative screening strategy, another one built with a positive screening strategy and a traditional one, argue that there is no significant relevance on the negative impact of SRI on returns and risk relative to traditional investments.

Auer and Schuhmacher (2016) analysed the financial performance in the geographic regions of Asia, Europe, and the United States between responsible investment funds and traditional investment funds and they compared it to the performance of a passive global stock market benchmark. The database used to consider ESG metrics is compiled by Sustainalytics, a Dutch-based rating agency that is a leader in sustainability analysis. The results show that, geographically and at industry level in Asia and the United States, adopting an investment strategy based on ESG scores does not underperform or outperform an investment strategy that does not take into account sustainable issues or the passive benchmark. However, as far as the European region is concerned, in certain industries being socially responsible could be costly as the risk-adjusted performance of the sustainable portfolio was significantly lower than the benchmark.

Verheyden et al. (2016) also studied the evolution of the financial performances by adopting an ESG-based strategy. They defined two different investable universes, the “Global All” which includes large-cap and middle-cap stocks in 23 developed markets and 23 emerging markets and the “Global Developed Markets (DM)” which involves exclusively large and mid-cap stocks in twenty-three developed markets. Using Sustainalytics ESG scores, the authors ranked the sustainability level of the companies and for each investable universe they created two portfolios implementing an ESG screening strategy. The negative screening strategies involved a cut 10% and 25% of stocks with the lowest ESG score. The results found that when comparing the portfolios to benchmarks which did not experience ESG screening, the ESG screening-based portfolios not only did not have a negative impact on financial performances but instead they had a positive risk-adjusted return improving the trade-off.

Van Duuren et al. (2016) conducted a survey to investigate whether conventional fund asset managers integrate ESG information into the investment process and how they use that information. The survey was filled out by 126 asset managers, and it was found that an increasing number of portfolio managers are considering ESG information in their investments and that ESG information is used more widely for stock selection, proving that SRI is growing dramatically. Surprisingly, a geographic effect on the use of ESG criteria was observed. In particular, American asset managers are less inclined to consider socially responsible investments and are sceptical about the financial performance that sustainable assets can generate. On the contrary, asset managers in Europe have been optimistic about the benefits that responsible investments can perform.

Gasser et al. (2017) have elaborated a portfolio optimisation model that incorporates ESG performance in combination with traditional financial performance metrics. The authors revisited Markowitz's model and "Portfolio Selection Theory" with the aim of creating a model that was not based merely on the return and risk of a specific asset but also on a socially responsible investment parameter. At a time in history when SRI has undergone rapid growth, the authors proposed a model that could ensure a three-dimensional asset allocation, guaranteeing to the investor a preference choice on the issue of sustainability. The analysis was conducted on approximately 6000 companies included in the Thompson Reuters Equity Global Index which it is also constituted by sustainable assets. In order to compute the sustainability parameters of each company, the Thompson Reuters ASSET4 Database was used.

The assumptions of the new model are the same assumptions mentioned earlier in the Markowitz model. In addition, the model was developed considering a defined set of preference parameters at the level of risk, return and sustainability. In theory, this new model proposes to maximise an objective function with three different parameters, then:

$$\max \alpha\mu + \gamma\theta - \beta\sigma^2,$$

where α, γ and β respectively represent the return preference, the sustainable preference and risk preference of an investor. $\mu = \sum_{i=1}^{n} \mu_i \omega_i$ denotes the sum of the weighted returns of the asset i, $\theta = \sum_{i=1}^{n} \theta_i \omega_i$ indicates the sum of the weighted ESG scores of each company i and $\sigma^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} \sigma_i \sigma_j \omega_i \omega_j \rho_{i,j}$ signifies the sum of weighted variances of each company in the portfolio, for each $i = 1, \dots, n$ and $j = 1, \dots, n$.

In this study, two optimised portfolios with different parameters were built: a traditional one which maximises the function that composes the Sharpe ratio and an ESG-based one that maximises the objective function that calculates the delta ratio. The Sharpe ratio of the portfolio is defined by $S_P = \frac{\mu_P - \mu_{rf}}{\sigma_P}$, where μ_{rf} represents the return of the risk-free rate; the delta ratio of the portfolio is given by $\delta_P = \frac{\theta_P}{\sigma_P}$.

The authors performed approximately twenty thousand simulations for the two optimised portfolios each consisting of 50 stocks. Not surprisingly, the traditional portfolio has been observed to have a significantly higher return but also a significantly higher risk than the ESG-based portfolio, and conversely the ESG-based portfolio has a higher sustainability metric than the traditional portfolio. However, it was also revealed that selecting a portfolio composed of SRI stocks does not have a significantly negative impact on financial performance compared to a portfolio that does not take ESG metrics into account in the asset selection process.

A similar analysis was undertaken by Chen et al. (2021) who studied the optimisation of a socially responsible portfolio in the United States industrial stock market for a period from 2005 to 2017. In this case, the authors, before performing portfolio optimisation, paid particular attention to asset selection and the interaction of financial performance with ESG performance. Firstly, instead of directly using the ESG scores provided by the ASSET4 database, a data enveloped analysis (DEA) was carried out to ensure greater interaction between the three individuals environmental, social and governance scores and assess their efficiency. Subsequently, the improved ESG scores were interacted with other business performance metrics such as asset utilization, liquidity, leverage, profitability, and growth in order to select assets for inclusion in the portfolio. Finally, they proceeded to portfolio optimisation by allocating assets with the purpose of maximising return and ESG score while minimising risk. The findings showed that the SRI portfolio for most of the years under analysis performed better in terms of risk, return, and sustainability than a conventional portfolio or the S&P 500 benchmark. In particular, it was pointed out that in the crisis conditions the SRI portfolio performed significantly better than other portfolios.

De Spiegeleer et al. (2021) developed a portfolio optimisation model that included ESG scores as a criterion for asset allocation. The study was implemented separately on the U.S. market with the Russell 1000 Index, and on the European market with the Stoxx Europe 600 Index, using ESG scores and greenhouse gas (GHG) emissions data provided by the MSCI rating agency. The authors have extended the traditional portfolio optimisation model designed by Markowitz by integrating sustainability into return and risk metrics. Therefore, they proposed a mean-variance model with variance minimisation as the objective function, a performance return target and a sustainability constraint. The mathematical visualization problem is then:

$$\min_{\omega \geq 0} \omega^T \Sigma \omega$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \mu = \mu_P,$$

$$\omega^T \gamma \leq \gamma_P.$$

Where μ_P is the target return that an investor wants to achieve and $\gamma = \gamma_1, \gamma_2, \ldots, \gamma_N$ represents the column vector of the sustainability level for each asset i, for each $i = 1, 2, \ldots, N$. In addition, a constraint $\omega \geq 0$ was placed so that the weights associated with the respective assets were never negative, thus creating a more realistic model which avoids short selling.

Alternatively, when an investor is more interested in the level of sustainability rather than the portfolio return, it is possible to create a green portfolio that guarantees a certain level of sustainability based on the investor's preferences. The so-called green-variance portfolio optimisation has as objective the minimisation of the variance function with the constraint of reaching a certain level of sustainability γ_P, without imposing any return constraint. So, the optimisation problem is given by:

$$\min_{\omega \geq 0} \omega^T \Sigma \omega$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \gamma = \gamma_P.$$

In any case, it is possible to add to the optimisation problem another constraint in order to guarantee the attainment of a minimum threshold of return by setting $\omega^T \mu \geq \mu_P$, where μ_P represents the minimum portfolio return level required.

The authors conducted the study on 552 stocks in the Stoxx Europe 600 Index and 914 stocks in the Russell 1000 Index selected in September 2019. Different types of portfolio strategies were compared with these stocks over a 10-year period, from 2009 to 2019. The minimum variance portfolio was compared to a "green portfolio" in which assets with the highest ESG scores are overweighted and a "brown portfolio" in which assets with low ESG performance are favoured. Overall, it emerged that over the entire time horizon the brown portfolio performed better in both the European and American markets with respect to other portfolios. However, it also turned out that the highest returns were mainly achieved in the early years of the study while, if only the last three years were considered, the cumulative returns of the green portfolio would grow more than the others. In addition, it was observed that in the European market, the risk of the green ESG portfolio is significantly lower than the brown portfolio, while, on the contrary, in the American market, the brown portfolio had a lower risk overall.

Pedersen et al. (2021) realized the ESG-efficient frontier, the efficient frontier subject to a given ESG constraint plotted in mean-variance plan. In their analysis, the authors implemented portfolios that maximised the Sharpe ratio subject to a given ESG constraint proving a narrowing of the efficient frontier. Furthermore, by analysing the financial performance of portfolios considering E, S and G scores individually, they showed that companies with high governance rate produce high returns.

Collectively, the literature concerning sustainable finance suggests that being a responsible investor does not necessarily come at a cost in terms of financial performance and in particular returns. Friede et al. (2015) published a meta-analysis of over 2,000 empirical ESG studies since the 1970s for the Deutsche Asset & Wealth Management and the Hamburg University which summarizes the relationship between ESG performance and corporate financial performance (CFP). So far, this study represents the most comprehensive review of academic research on the sustainable investments' topic. The analysis highlights that most research shows a positive relationship between ESG and corporate financial performance stable over time. According to the authors, “Roughly 90 percent of studies find a non-negative ESG–CFP relation. More importantly, the large majority of studies reports positive findings.”. The results produced by this study are therefore the opposite of what is perceived by investors, showing that socially responsible investment, especially with a long-term view, can prove to be an excellent investment strategy in terms of both sustainability and financial performance.

Chapter 3

Empirical analysis

3.1 Data

3.1.1 The Stoxx Europe 600

The investable universe from which the companies have been selected for the implementation of the empirical analysis is the Stoxx Europe 600 index. The Stoxx Europe 600 is an equity index created in 1998. It is a sub-group of the Stoxx Global 1800 equity index supplied by a Swiss provider. The index is composed by a fixed number of companies equal to six hundred. The constituents are selected from seventeen different European countries[7] and they cover roughly the 90% of the total capitalization of the entire European market[8]. Before joining the equity index, shares of each company are distinctively assigned to a unique country and a single market quotation based on criteria dependent by the country in which the company was constituted, the country in which the company is principally listed and the country in which the largest volume of transactions take place. The Stoxx Europe 600 is constantly rebalanced on a quarterly basis in March, June, September, and December: the provider deals with creating a list of selectable stocks from which these stocks are chosen to constitute the equity index and to replace those stocks that quarterly leave the index. The selection list is established based on the most recent data available at the Stoxx rebalancing date. The components of the index are the six hundred largest companies in terms of free-float market capitalization; for each company only the most liquid stock is considered.

In order to determine the weight that each individual company has on the Stoxx index, a free-float factor is given to each stock to reduce the total number of shares and to determine the portion of the company's shares available to the public. Weights on the Stoxx Europe 600 Index are determined based on the free-float market capitalization of each stock.

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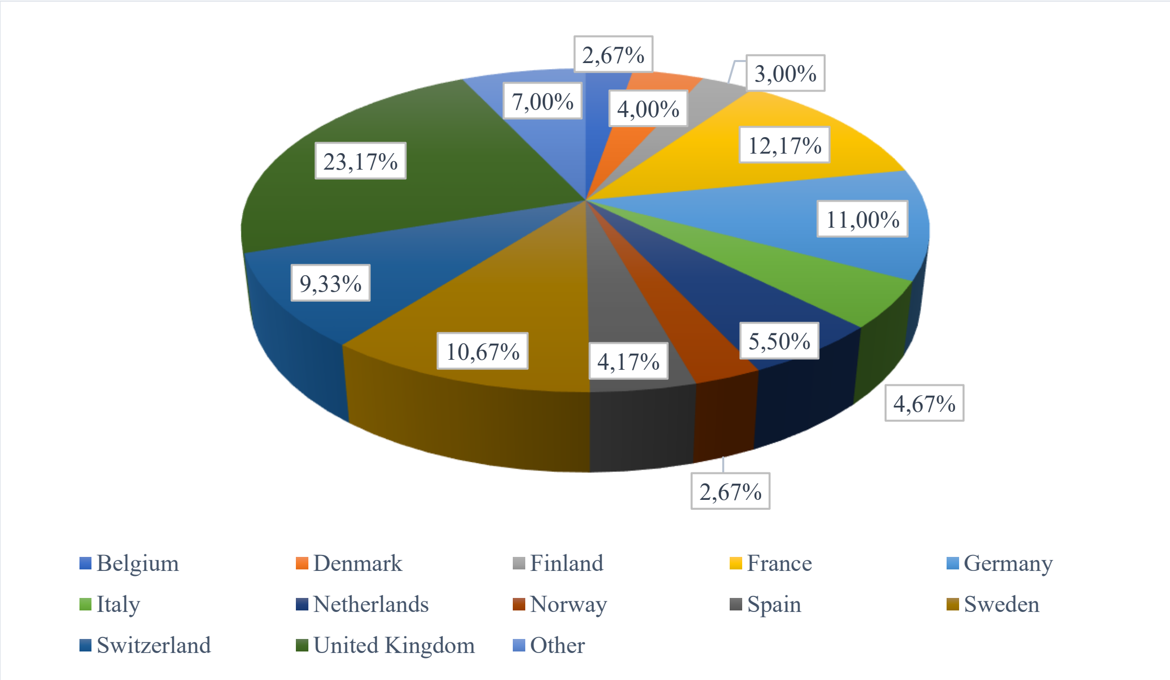
[7] Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, United Kingdom. If other years prior to 2022 are also considered, companies based in the Czech Republic, Cyprus, Greece, and Malta were included in the Stoxx Europe 600.

[8] Source: Stoxx Index Methodology Guide

The Figure 4 shows the composition of the Stoxx Europe 600 Index from the geographic view as of 31 December 2021. Almost 60% of the total companies which constituted the index are headquartered or listed in the United Kingdom, France, Germany, and Sweden. Companies located in Austria, Ireland, Luxembourg, Poland, and Portugal represented singularly less than the 2% of the total, so we grouped them together and labelled as "Other".

Figure 4: Stoxx Europe 600 Country view 31-12-2021

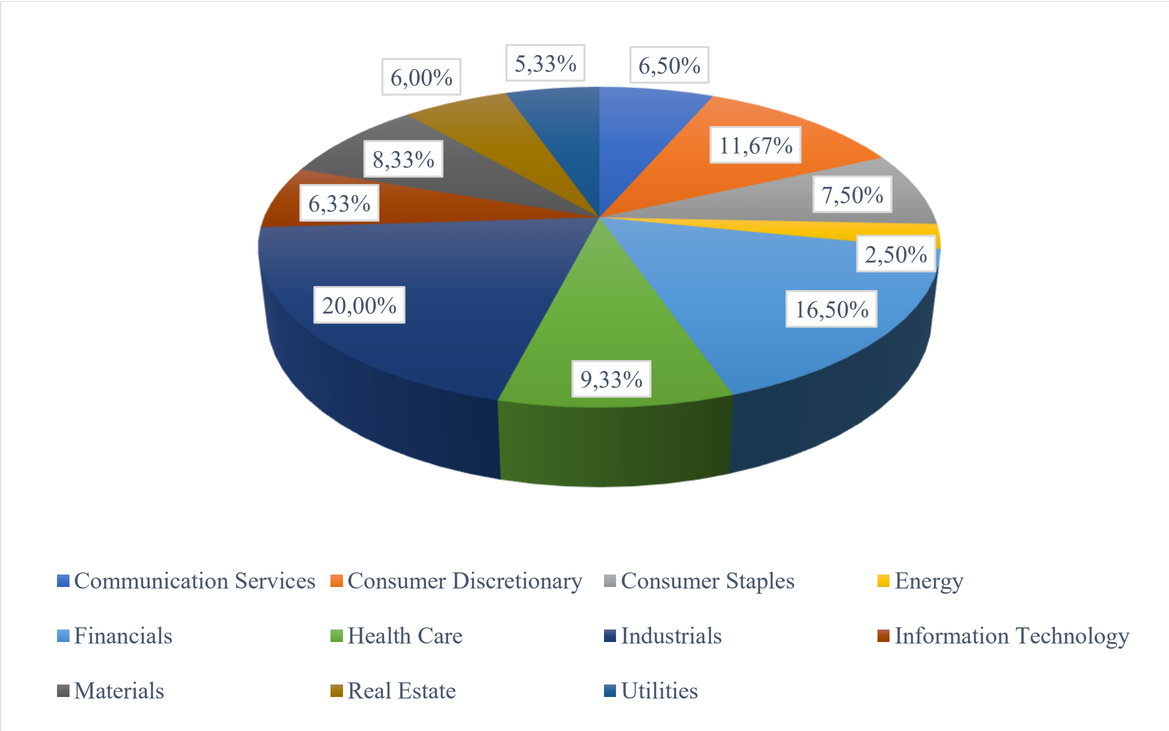


Companies in the Stoxx Europe 600 Index are also categorized in macro sectors according to the Global Industries Classification Standards (GICS). The eleven sectors provide by the universally acknowledged classification are:

- Communication Services;
- Consumer Discretionary;
- Consumer Staples;
- Energy;
- Financials;
- Health Care;
- Industrials;
- Information Technology;
- Materials;
- Real Estate;
- Utilities.

The Figure 5[9] shows the Stoxx Europe 600 composition from the sector view as of 31 December 2021. The macro-sectors that include a greater number of companies in the index are Industrials sector with 120 companies, Financials sector with 99 companies and Consumer Discretionary sector with 70 companies.

Figure 5: Stoxx Europe 600 Industry view 31-12-2021



3.1.2 ESG score methodology

With the aim of defining the sustainability level of each company in our investment universe, we used the ESG scores retrieved from the Thompson Reuters ESG database[10] or Refinitive ESG database. Thompson Reuters ESG database in one of the most important databases worldwide employed; it provides an ESG rating service of nearly 9000 companies globally located. Thomson Reuters ESG scores are calculated according to a specific method to give investors a clear and transparent overview on the sustainability rating of a precise company. The composition of the ESG scores is based on three pillars: the environmental pillar, the social pillar and the governance pillar. Each pillar is divided into three or four different

[9] The pie charts in the Figures 4 and Figure 5 have been built with data retrieved from Thompson Reuters Database on the 5th of February 2022.

[10] Thompson Reuters ESG database is also known as the most popular Asset4 database. Thompson Reuters acquired Asset4 database, the Swiss provider of environmental, social and governance (ESG) data, in 2009.

subsets called categories. The subgroups of the environment pillar are *emissions*, *innovation,* and *resource use*; the subgroups of the social pillar are *workforce*, *human rights*, *community* and *product responsibility*; the subgroups of the governance pillar are *management*, *shareholder* and *CSR strategy*. The ten categories are in turn divided into other metrics; overall the database designed ESG scores based on over 500 ESG performance metrics obtained from the public data disclosure of each company.

The ESG score is computed applying a weighted average of the value assumed by each of the three pillars. Weights are established based on the sectors to which the companies belong[11]. In turn, the value assumed by each pillar is determined by the weighted average of the values assumed by its own categories. The weights for the categories pertaining the environmental and social pillars depend on the sectors to which the companies belong, as in the calculation of pillars scores. While for the categories belonging to the governance pillar, the differentiation of weights by sector is not adopted but the weights remain the same for all industries. As it is shown in Table 1, the final ESG score could be rated in a range between 0 and 100, the higher is the ESG score the higher is the ESG performance of the company assessed. A grade, rated between D– and A+, is assigned to each given numerical interval.

Table 1: ESG score range and grade[12]

Score range	**Grade**
$0.00 \leq score \leq 8.33$	D -
$8.33 < score \leq 16.66$	D
$16.66 < score \leq 25.00$	D +
$25.00 < score \leq 33.33$	C -
$33.33 < score \leq 41.66$	C
$41.66 < score \leq 50.00$	C +
$50.00 < score \leq 58.33$	B -
$58.33 < score \leq 66.66$	B
$66.66 < score \leq 75.00$	B +
$75.00 < score \leq 83.33$	A -
$83.33 < score \leq 91.66$	A
$91.66 < score \leq 100$	A +

[11] Source: Refinitive

[12] The table was built utilizing Refinitive ESG database information.

In accordance with Triguero et al. (2016) which defined four distinct types of companies based on their investments in green innovations, we distinguish four categories of companies on the basis of the ESG score. Companies rated with the grade "*D*" are identified as laggards. Laggards represents business with weak ESG performance and a severe lack of transparency in public reporting of ESG information. Companied rated with a "*C*" are named loungers, they provide a modest transparency in ESG information reported and an adequate ESG performance. Firms with a good level of transparency in terms of public ESG information and with decent level of ESG performance are rated with a "*B*" and defined as followers. Lastly, companies rated with an "*A*" are classified as leaders. ESG leaders' companies exhibit an excellent level of transparency in ESG data publicly reported and a high degree of ESG performance.

3.1.3 Datasets composition

In this study, we collected data on companies included in the Stoxx Europe 600 Index. Firstly, we retrieved from Thompson Reuters database the list of companies included in the index at the end of each year from 2010 to 2020. It is important to highlight that firms entered the index during the year but exited it before December 31 of the same year were not accounted for the study. Eventually, we collected a list of six hundred companies for each year considered. The companies delisted at the time the data was downloaded[13] have been excluded from our study. The final dataset is composed by 827 companies located in twenty-one different European countries.

Subsequently, we downloaded from Thompson Reuters database the companies' time series prices in Euros of the last sixteen years on a weekly basis. The time series started from the 1st of January 2006 to the 31st of December 2021 resulting in 832 observations of prices. In order to standardize all the currencies in Euros, the prices of companies located in countries that have not adopted the euro have been converted into euros applying the weekly exchange rate equivalent to the corresponding date.

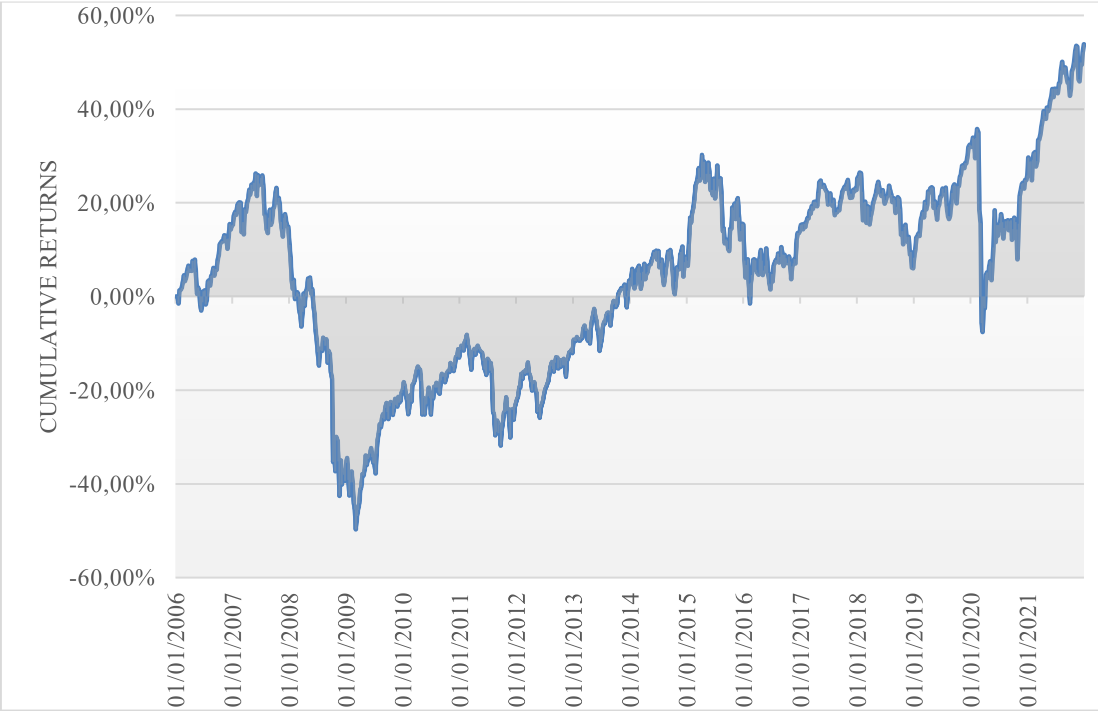
In addition, we retrieved the annual ESG scores on the 31st of December from 2010 to 2020 as measure of the environmental, social and governance performances of each company.

Figure 6 shows the historical pattern of the Stoxx Europe 600 benchmark from the 1st of January 2006 to the 31st of December 2021. The data used to produce the graph are the time

[13] The list of companies has been retrieved on the 7th of March 2022

series of weekly prices from which weekly returns and ultimately cumulative returns have been computed.

Figure 6: Weekly cumulative returns of Stoxx Europe 600



Our analysis on the historical performance was conducted firstly on a dataset (hereinafter dataset 0) using the most recent data available. Dataset 0 is composed by the companies included in the Stoxx Europe 600 index in 2020. Each company included in dataset 0 comprises a fifteen-year weekly price history series from January 1st of 2006 to December 31st of 2020[14]. The time series are used to calculate descriptive statistics while ESG scores, dated to 2020, to calculate portfolio sustainability performance.

To check the effectiveness and validity of the identified strategies, we implemented our analysis also on other different subsets. We created eleven different subsets based on the full investable universe of 827 companies. Every subset includes the companies that were listed in the Stoxx Europe 600 at the end of each year starting from 2010 to 2020. The eleven subsets were numbered from 1 to 11. Subset 1 comprises the companies included in the Stoxx at the end of 2010, subset 2 comprises the companies included in the Stoxx at the end of 2011, and so on so forth. Every subset collects time series' data on the weekly prices of the included companies over a period of five years, i.e. the five years preceding 31st December of the year

[14] The decision not to consider the year 2021 is because the annual ESG scores of the companies that constituted the Stoxx Europe 600 in 2021 were not yet available.

in which the Stoxx Europe 600 includes those companies. To provide an example, the Italian company A2A SpA, listed in the Stoxx Europe 600 index at the end of 2010, was included in subset 1, and the period considered for the calculation of its expected return and risk ranges from 1st January 2006 until 31st December 2010. In the case that the weekly prices' time series did not cover entirely the 5 years period used for the calculation of the statistics, then the company was removed from the subset.

The computation of companies' ESG performance is based on the year in which the companies were recorded in the European index. Using the same example mentioned above, the sustainability performance of A2A SpA, which was listed in the Stoxx Europe 600 at the end of 2010, was computed by using the 2010 ESG Score. An ESG score equal to 0 was assumed for companies that were not rated in that specific year[15].

Below, in Table 2, we have summarized the information provided above about the data composition of each subset.

Table 2: Subsets key information

Subsets	N. of companies included	Time series period	ESG score period
1	471	2006 - 2010	2010
2	474	2007 - 2011	2011
3	480	2008 - 2012	2012
4	476	2009 - 2013	2013
5	479	2010 - 2014	2014
6	494	2011 - 2015	2015
7	488	2012 - 2016	2016
8	485	2013 - 2017	2017
9	513	2014 - 2018	2018
10	531	2015 - 2019	2019
11	544	2016 - 2020	2020

The subsets just discussed will be employed in Chapter 4 on strategies backtesting, in which we will compare in-sample and out-of-sample financial and sustainability metrics.

[15] The reason behind this assumption is that Thompson Reuters assesses corporate ESG performance based on a company's Corporate Social Responsibility reports. The absence of transparency or the lack of these reports therefore assume an extremely low ESG score.

3.2 Data elaboration

Dataset 0 was cleaned of firms that were delisted and companies that did not include a long enough time series to cover all the fifteen years. Following this criterion, a matrix 780×467 was created, where 780 is the number of weeks in 15 years of time and 467 is the number of companies used for the analysis.

Similarly, each subset was cleaned of delisted companies and companies that did not have a price history long enough to cover 5 years of time. Matrices $260 \times N$, were created with the weekly historical series of prices of the companies. 260 corresponds to the number of weeks that constitute 5 years of time, while N is the number of companies in each subset.

Weekly returns for each company were calculated with natural logarithms using the formula $r_{i,t} = ln\left(\frac{P_t}{P_{t-1}}\right) = ln(P_t) - ln(P_{t-1})$, where $r_{i,t}$ symbolise the return at time t of the company i, P_t represents the price at time t of a specific company i, while P_{t-1} denotes the price of the company i at the time $t-1$, which it means the week before the week identified at time t. The reason for choosing to employ natural logarithms in the calculation of price returns in time series arises from the assumption that the time series has a normal probability distribution. Indeed, as Lütkepohl and Xu (2012) studied, the logarithmic transformation of a time series allows to normalize its probability distribution and stabilize its variance. Moreover, the logarithmic formula for calculating returns can be approximated to the traditional formula, since $ln\left(\frac{P_t}{P_{t-1}}\right) \approx \frac{P_t - P_{t-1}}{P_{t-1}} = \frac{P_t}{P_{t-1}} - 1$.

In order to obtain the parameters to be able to proceed with portfolio optimisation in the dataset 0 and in each subset, the return, the risk of each company and the dependency of one company on the others were computed through sample estimation. Therefore, after calculating the logarithmic returns of each firm and the benchmark, we calculated the average of weekly returns, the variance of the weekly returns, and the covariance of the returns of firm i with the returns of firm j. These sample moments are respectively defined by the formulas:

- $\mu_i = \frac{1}{T}\sum_{t=1}^{T} r_t$;
- $\sigma_i^2 = \frac{1}{T-1}\sum_{t=1}^{T}(r_t - \mu)^2$;
- $\sigma_{i,j} = \frac{1}{T-1}\sum_{t=1}^{T}(r_{i,t} - \mu_i)(r_{j,t} - \mu_j)$, where $t = 1, \dots, T$.

Lastly, we annualized the sample moments multiplying the results for the number of weeks over the years and we created the variance-covariance matrix Σ, an $N \times N$ matrix where N is the number of companies in the sample of companies. So, in each subset we have:

- the expected return $E(\mu_i) = \left(\frac{1}{T}\sum_{t=1}^{T} r_t\right) \times \left(\frac{n_{weeks}}{n_{years}}\right)$, for each company i,
- the variance-covariance matrix $\Sigma = \begin{pmatrix} \sigma_1^2 & \cdots & \sigma_{1,N} \\ \vdots & \ddots & \vdots \\ \sigma_{N,1} & \cdots & \sigma_N^2 \end{pmatrix}$,

where variances and covariances in the matrix are annualized respectively by the formula $\sigma_i^2 = \frac{1}{T-1}\sum_{t=1}^{T}(r_t - \mu)^2 \times \left(\frac{n_{weeks}}{n_{years}}\right)$, and $\sigma_{i,j} = \frac{1}{T-1}\sum_{t=1}^{T}(r_{i,t} - \mu_i)(r_{j,t} - \mu_j) \times \left(\frac{n_{weeks}}{n_{years}}\right)$.

3.3 Allocation strategies

The choice of a specific strategy to be implemented is particularly important for the creation of a portfolio as it determines the amount of wealth to be invested in each asset in a way that meets the preferences of the investor. The traditional literature has provided us with numerous asset allocation strategies which we used to perform our empirical analysis. Four different strategies have been adopted, the equally weighted strategy, the minimum variance strategy, the maximum trade-off strategy, and the maximum delta ratio strategy. While the equally weighted strategy is simply implemented as a benchmark since it does not derive from a function optimisation, the other three strategies optimise a specific function that highlights a particular aspect in which a hypothetical investor may be interested, i.e., the risk, the return, or the sustainability.

The application of each strategy to portfolios ignores transaction costs, brokerage costs and capital gains taxes, as the purpose of the study is to focus on the differences in performance of traditional portfolios and portfolios that incorporate the ESG factor.

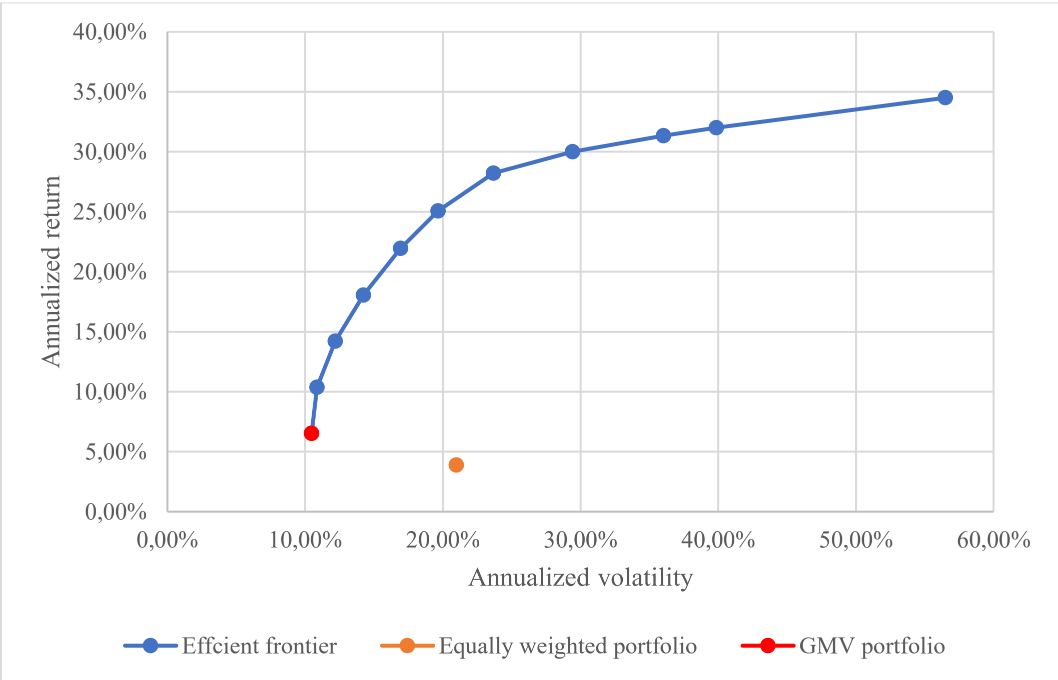
We conducted the analysis mainly in Excel. The cleaning of datasets, the calculation of descriptive statistics for each company and the construction of variance-covariance matrices are simple operations that do not require special software. On the other hand, portfolio optimisations were performed with Matlab software. The solver, Excel tool, is not powerful enough when it involves determining the optimal vector of weights to implement the optimisation strategy. In particular, the maximum capacity of variables to solve a nonlinear function is two hundred. Our number of variables, equal to the number of firms contained in each subset, is larger.

For each allocation strategy that required an optimisation of a specific objective function, the code was written in Matlab. The codes are described in Appendix 2.

3.3.1 Equally weighted

The equally weighted is one of the simplest portfolio allocation strategies because it does not require the involvement of special software or the execution of complex calculations. The basic idea behind the strategy of equally weighted allocation is to set the same weight on each asset in the portfolio and, so, divide the wealth to be invested in equal parts for each asset. In our analysis, therefore, the equally weighted is the unique strategy that does not perform a study on the historical return, risk and ESG performance of the companies included in the dataset. Therefore, the vector of optimal weights ω^* is calculated as $\omega_1, \omega_2, \dots, \omega_N = \frac{1}{N}$, where N is the number of assets in the portfolio. Within this framework, the equally weighted portfolio is considered inefficient since it does not optimise a specific function imposing a return, risk, or sustainability target. Figure 7 shows graphically the inefficiency of the equally weighted portfolio proving that effective wealth allocation leads to portfolios with higher returns and lower risks.

Figure 7: Equally weighted portfolio in the mean-variance plan[16]



Even though this allocation strategy is considered obsolete and inefficient by the literature, as shown by some studies, it is found that this type of portfolio obtains better performance out-of-sample than traditional optimisation strategies. DeMiguel et al. (2009) have compared the

[16] The data used to compute the statistics and plot the figure are based on a fifteen period from 2006 to 2020.

equally weighted strategy with other traditional performance optimisation strategies. Although they performed a calculation that optimised performance in a specific period (in-sample-period), the same performance was not met when the strategy was applied for the immediately following period (out-of-sample period). The result highlights how sample estimation of the moments of asset returns can be biased.

3.3.2 Global Minimum Variance

The Global Minimum Variance (GMV) is a strategy implemented for the first time by Markowitz, the father of the Modern Portfolio Theory. This investment strategy can be adopted by an investor who is risk averse and does not have a minimum return objective as the portfolio is optimised by minimising the variance. We have implemented four different minimum variance strategies, two traditional and two that include in the constraints the achievement of a certain threshold of ESG performance.

The *Global Minimum Variance* or GMV portfolio created concerns to minimise the variance by imposing positive weights as a constraint in order to avoid short selling which is considered a very risky practice and the possibility of obtaining extreme weights. So, the mathematical representation of the problem is the following:

$$\min_{\omega \epsilon \mathbb{R}^N} \omega^T \Sigma \omega,$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$
$$\omega \geq 0,$$

where $\sigma_P^2 = \omega^T \Sigma \omega$ exemplifies the variance of the portfolio P. The output of the optimisation is the optimal weight vector ω^* that enables the minimisation of the variance. However, the strategy could produce exceptionally high weights to a few risky assets and set the others to zero, risking over-concentration of the total wealth in a specific asset. With the aim of avoiding excessive concentration in assets, the *GMV constrained* portfolio was introduced.

In the *GMV constrained* portfolio, a maximum limit of 10% and minimum limit of 0.01% have been imposed to the optimal weights ω_i^*. This strategy ensures the integration of all assets within the portfolio. The optimisation problem is then:

$$\min_{\omega \in \mathbb{R}^N} \omega^T \Sigma \omega,$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$0.01\% \leq \omega \leq 10\%.$$

The minimum variance strategy has been modified by introducing among the constraints the achievement of a minimum threshold of ESG performance γ_P. So, the *Minimum Variance ESG (MV ESG)* portfolio integrates the optimisation of classical financial metrics with ESG performance.

The *Minimum Variance ESG* portfolio minimises the variance as in the traditional strategy, but it sets a sustainability constraint by imposing ESG portfolio score higher than 75.00. By introducing this type of constraint, the efficient frontier will be modified and the portfolio, therefore, will not reach the global minimum variance.

The choice of enforcing this type of constraint on ESG performance derives from the willing to create an ESG leader portfolio. Indeed, as previously mentioned in section 3.1.2, companies are assigned a grade from D to A based on ESG scores. The minimum threshold to reach a grade of A is an ESG score higher than 75.00. The optimisation problem is displayed as:

$$\min_{\omega \in \mathbb{R}^N} \omega^T \Sigma \omega,$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \gamma > 75.00,$$

$$\omega \geq 0,$$

where $\gamma = \gamma_1, \gamma_2, \dots, \gamma_N$ is the column vector of the ESG performance of the company i, with $i = 1, 2, \dots, N$ and $\gamma_P = \omega^T \gamma$ represents the ESG score of the portfolio P.

As with the traditional strategy, maximum and minimum constraints on optimal weights are imposed on the MV ESG portfolio. In this case the optimisation problem is as follows:

$$\min_{\omega \in \mathbb{R}^N} \omega^T \Sigma \omega,$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \gamma > 75.00,$$

$$0.01\% \leq \omega \leq 10\%.$$

With this strategy, the *MV ESG constrained* portfolio imposes a maximum limit of 10% to the wealth to be invested in a company and a minimum limit of 0.01% to the wealth be invested in each company, guaranteeing in any case the achievement of the ESG threshold higher than 75.00.

3.3.2 Maximum trade-off

The Maximum trade-off is an optimisation strategy which maximise the ratio between the return of the portfolio and its risk, represented by the standard deviation of the returns. This strategy also considers the return factor in addition to portfolio risk and is riskier than the GMV strategy since it does not minimise variance. As with the previous strategy, four different portfolios were implemented with constraints on optimal weights and ESG portfolio performance.

The *Maximum trade-off* portfolio maximises the return-to-risk ratio by imposing positive optimal weights constraint, so as to avoid short-selling and extreme weights that might be related with the companies. The portfolio optimisation problem is presented as:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \mu}{\sqrt{\omega^T \Sigma \omega}},$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega \geq 0,$$

where $\mu_P = \omega^T \mu$ represents the return and $\sigma_P = \sqrt{\omega^T \Sigma \omega}$ denotes the risk of the portfolio P. The *Maximum trade-off* portfolio does not have constraints that require a minimum weight greater than zero to attribute to the optimal weights ω_i^*, outputs of the problem. So, the results of the optimisation problem could lead to a portfolio constituted from a small number of risky assets. To avoid over-concentration of assets, we implemented the Maximum trade-off constrained portfolio.

The *Maximum trade-off constrained* portfolio maximises the relationship between return and risk but restricts the efficient frontier in such a way that all available assets in the dataset are considered in the portfolio. The creation of this portfolio involves the imposition of a maximum and minimum bound to the output vector of the optimal weights. In fact, a minimum of 0.01% and a maximum of 10% is invested in each risky asset. So, the mathematical representation of the optimisation problem is:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \mu}{\sqrt{\omega^T \Sigma \omega}},$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$0.01\% \leq \omega \leq 10\%.$$

For investors with certain sustainability goals, the maximum trade-off strategy was set with a constraint that would allow the portfolio to incorporate ESG performance.

The *Maximum trade-off ESG* portfolio maximises the ratio between the return and the risk of the portfolio but also includes the achievement of an ESG performance threshold that classifies it as a ESG leader portfolio. The optimisation problem to be solved is characterised as follows:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \mu}{\sqrt{\omega^T \Sigma \omega}},$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \gamma > 75.00,$$

$$\omega \geq 0,$$

where $\gamma_P = \omega^T \gamma$ represents the ESG score of the portfolio P and $\gamma = \gamma_1, \gamma_2, \ldots, \gamma_N$ is the column vector of the ESG performance of the company i, with $i = 1, 2, \ldots, N$.

Even that portfolio risks to allocate wealth in a few risky assets whose financial metrics have performed reasonably well over the time analysed and with high ESG scores.

The *Maximum trade-off ESG constrained* strategy ensures the integration of all assets within the portfolio, and it avoid over-concentration by imposing a minimum weight of 0.01% and a maximum weight of 10% for each asset. The problem is therefore:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \mu}{\sqrt{\omega^T \Sigma \omega}},$$

subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega^T \gamma > 75.00,$$

$$0.01\% \leq \omega \leq 10\%.$$

Solving this optimisation problem guarantees a portfolio with an adequate return-to-risk ratio, an important level of ESG performance and a reasonable diversification of risky assets.

3.3.3 Maximum delta ratio

The maximum delta ratio is a strategy that maximises the portfolio delta ratio $\theta_P = \frac{\gamma_P}{\sigma_P}$ given by the ratio of ESG score to portfolio risk. This strategy does not consider the portfolio returns but rather focuses on ESG performance and volatility. It is optimal for an investor with a risk-averse profile and interested in achieving a high sustainability threshold.

The *Maximum delta ratio* portfolio maximises the ratio between ESG score and standard deviation of the portfolio setting positive optimal weights as constraint of output the vector. Under these conditions the problem of optimisation is:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \gamma}{\sqrt{\omega^T \Sigma \omega}},$$

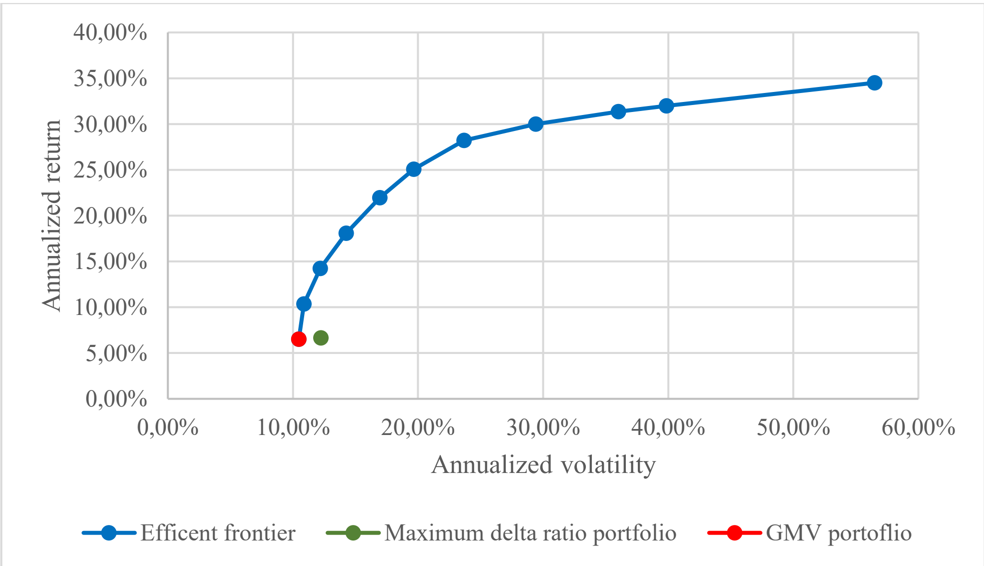
subject to the constraints

$$\omega^T \mathbf{1} = 1,$$

$$\omega \geq 0,$$

where $\gamma_P = \omega^T \gamma$ is the ESG score and $\sigma_P = \sqrt{\omega^T \Sigma \omega}$ is the standard deviation of the portfolio P. As in the previous strategies, the maximum delta ratio strategy may lead to a portfolio composed by a modest number of risky assets. The risk of a strategy that includes few assets in the portfolio could lead to poor future performance that does not meet expectations. Rationally, since this optimisation problem aims to maximise a criterion that is not part of the mean-variance framework, this type of portfolio is also not considered efficient. Figure 8 shows the Maximum delta ratio portfolio from a risk-return view.

Figure 8: Maximum delta ratio portfolio in the mean-variance plan



The *Maximum delta ratio constrained* portfolio guarantees the possibility to invest a fraction of wealth in each risky asset in the investable universe avoiding over-concentration of the wealth in an asset. As in the GMV strategy and in the maximum trade-off strategy, the boundaries of the optimal weights are between the 0.01% and the 10%. Below is shown the mathematical representation of the problem:

$$\max_{\omega \epsilon \mathbb{R}^N} \frac{\omega^T \gamma}{\sqrt{\omega^T \Sigma \omega}},$$

subject to the constraints

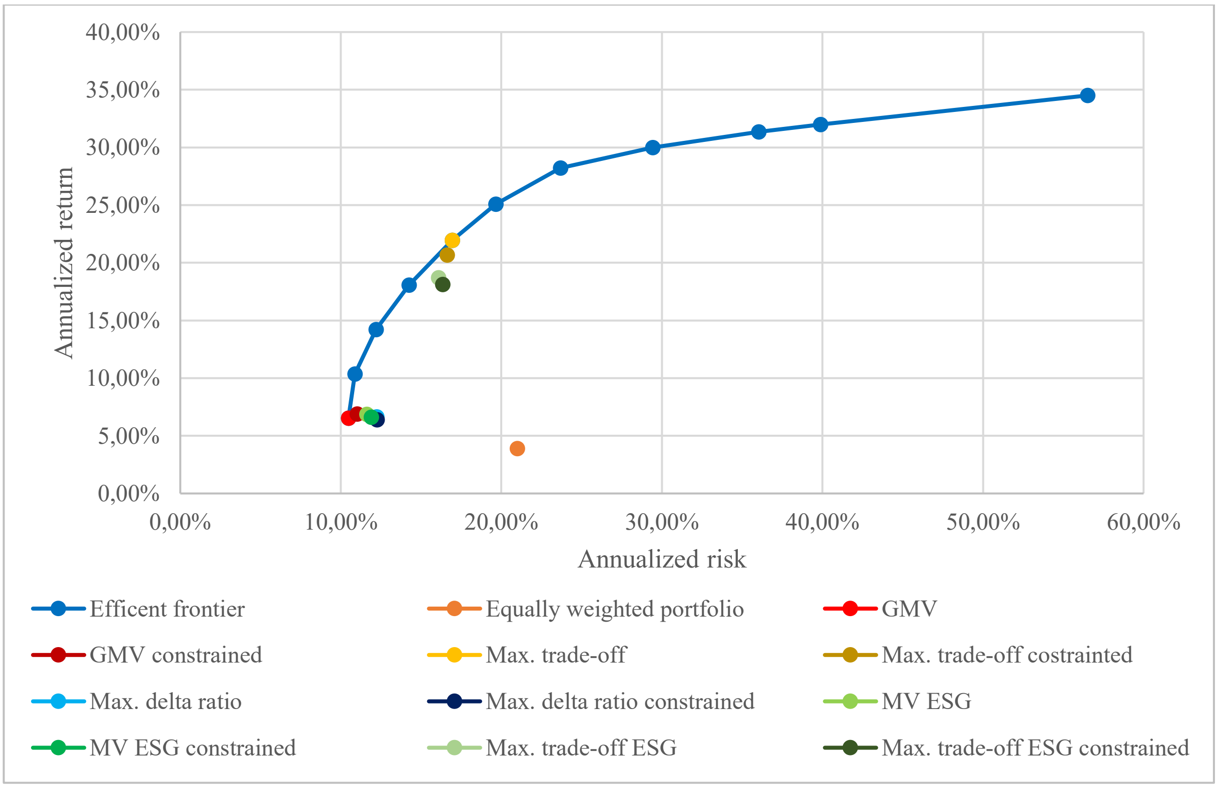
$$\omega^T \mathbf{1} = 1,$$

$$0.01\% \leq \omega \leq 10\%.$$

Logically, sustainability constraints were not applied to portfolios created with this strategy, as the portfolio ESG considerations was already included in the objective function.

To sum up, we represented the efficient frontier with all the strategies above-mentioned. As shown in the Figure 9, the only portfolios that are part of the efficient frontier are the GMV and the Maximum trade-off. The other strategies, because of the constraints imposed on optimal weights and/or on the sustainability level, do not laid on the frontier.

Figure 9: Strategies in the mean-variance plan



3.4 Results

In this section we reported the results of the strategies implemented on dataset 0. For each strategy, we computed the expected return, the expected volatility, and the ESG score. Moreover, we calculated the Sharpe ratio and the delta ratio respectively as financial and sustainability performance measurers. Additionally, we also reported the results obtained by conducted our analysis on the eleven subsets.

The Sharpe ratio is one of the most common measures to evaluate the portfolio financial metrics. It was introduced by William Sharpe (1966) as "reward-to-variability ratio", a performance indicator to evaluate mutual funds performances. The Sharpe indicator is determined by the ratio of a portfolio's excess return to its volatility. The excess return of a portfolio is the difference between the portfolio return and the risk-free rate return. Mathematically, it is defined by the formula:

$$Sr_P = \frac{E(r_P)}{\sigma_P}.$$

$E(r_P) = r_p - r_f$, where r_p is the portfolio return and r_f is the risk-free rate. The risk-free rate we used to calculate the Sharpe ratios of the portfolios is euro short-term rate (€STR), which for simplicity we assumed to be constant over time and equal to 0.01.

The delta ratio is a performance measure that has been introduced in the recent literature following the incorporation of the sustainability criterion into asset selection and allocation. The delta ratio is an indicator given by the ratio of a portfolio's ESG score to its risk. Mathematically, it is defined by the formula:

$$\theta_P = \frac{\gamma_P}{\sigma_P},$$

where γ_P is the portfolio ESG performance.

3.4.1 Dataset 0

The dataset 0 is composed by the companies that comprise a fifteen-year time series of prices. Table 3 summarizes the results obtained in our analysis. The table shows the descriptive statistics of the *Equally weighted* portfolio and the portfolios resulting from solving the constrained optimisation problems. The optimisation strategies implemented, explained in section 3.3, are *Global Minimum Variance (GMV)*, *Global Minimum Variance constrained*, *Maximum trade-off*, *Maximum trade-off constrained*, *Maximum delta ratio*, *Maximum delta ratio constrained*, *Minimum Variance ESG (MV ESG)*, *Minimum Variance ESG constrained*, *Maximum trade-off ESG*, and *Maximum trade-off ESG constrained*.

Moreover, we reported the expected annualized return and the annualized volatility of the Stoxx Europe 600.

Table 3: Summary results of strategies implemented in dataset 0

Strategy	Expected annualized return	Annualized volatility	ESG score	Sharpe Ratio	Delta ratio
Stoxx Europe 600	0,57%	20,24%	-	-0,02	-
Equally weighted	3,89%	20,99%	70,30	0,14	334,97
GMV	6,52%	10,47%	56,14	0,53	536,03
GMV *constrained*	6,90%	11,02%	61,19	0,53	555,02
Max. trade-off	21,95%	16,94%	57,41	1,24	338,97
Max. trade-off *constrained*	20,66%	16,62%	57,89	1,18	348,42
Max. delta ratio	6,64%	12,23%	79,44	0,46	649,35
Max. delta ratio *constrained*	6,40%	12,26%	77,57	0,44	632,89
Min. Variance ESG	6,86%	11,61%	75,01	0,50	645,84
Min. Variance ESG *constrained*	6,61%	11,90%	75,01	0,47	630,55
Max. trade-off ESG	18,70%	16,07%	75,01	1,10	466,65
Max. trade-off ESG *constrained*	18,12%	16,33%	75,01	1,05	459,28

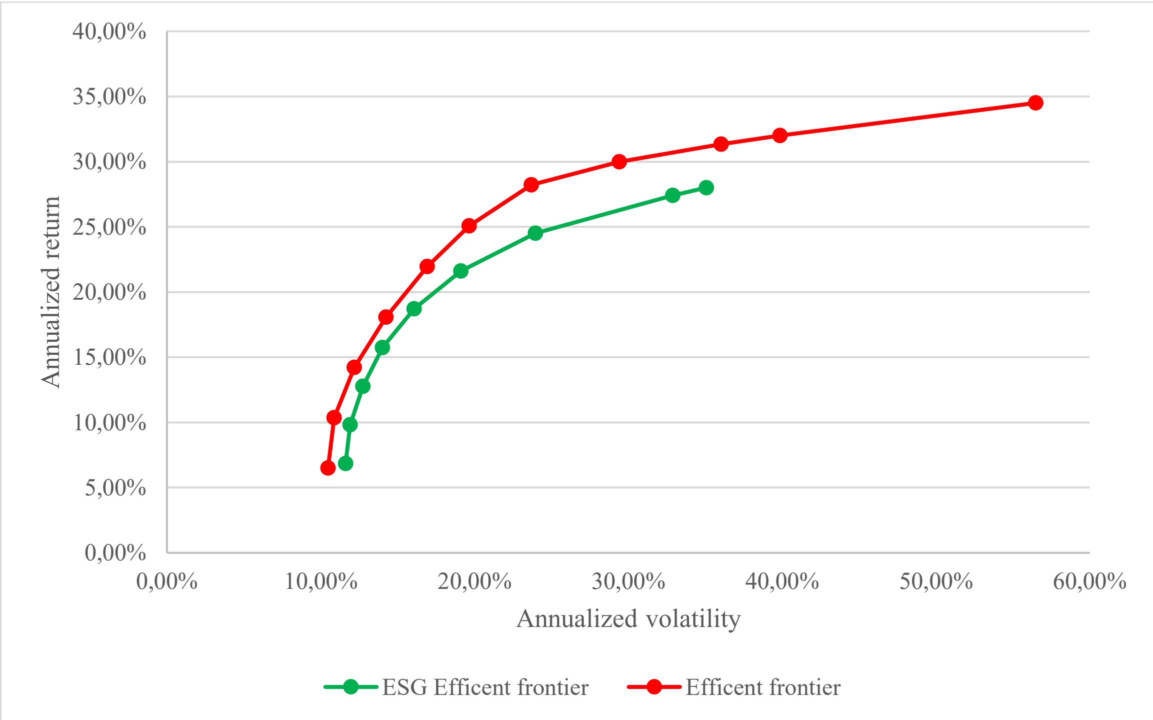
Not surprisingly, strategies that aimed at optimising a particular performance metric outperformed the market benchmark and the equally weighted portfolio. Traditional allocation strategies, which focus exclusively on financial performance metrics, were found to give insufficient attention to environmental, social and governance parameters. Table 3 reveals that traditional portfolios can be classified as ESG followers since the ESG score is ranked between 50 and 75 but never as ESG leader. The strategies that performed the worst in terms of ESG performance were *Maximum trade-off* and *Maximum trade-off constrained* which had the lowest portfolio ESG score. However, the *Equally weighted* portfolio obtained the lowest delta ratio due to its higher risk with respect to maximum trade-off strategies.

Overall, the strategy that clearly achieved the lowest annualized standard deviation is *GMV* portfolio where portfolio risk is equal to 10.47%. On the other hand, the strategy that reached the highest annualized return is *Maximum trade-off* portfolio with an average annualized return of 21.95%. Comprehensibly, this strategy achieved the highest Sharpe ratio equal to 1.24. The portfolio that accomplished the highest ESG score is the *Maximum delta ratio* which measures an environmental, social and governance performance equal to 79.44. By definition, this is the portfolio with the highest delta ratio equal to 649.35.

From the results obtained on performances in the mean-variance framework between traditional allocation strategies and sustainable strategies, it is clear that traditional strategies achieve significantly better financial metrics than SRI strategies. Indeed, as confirmed by Pedersen et al. (2021), the imposition of the sustainability constraint implies a narrowing of the efficient frontier, which is the set of all optimal portfolios that can be obtained by varying the risk-return preferences of an investor.

Figure 10, based on the historical performances of dataset 0, reveals the difference between the efficient frontier created by implementing solely weights greater than or equal to zero as a constraint and the efficient frontier that additionally reaches an ESG portfolio score greater than 75.00 as a sustainability constraint.

Figure 10: Comparison between the traditional efficient frontier and ESG efficient frontier



Every time a new constraint is added in the mean-variance optimisation, the efficient frontier shrinks. So, the application of the same strategies implemented in the traditional mean-variance model with an additional sustainability constraint result in a decrease in financial performance.

Figure 11 summarizes graphically the performance metrics of all the optimisation strategies implemented. The figure provides a visual insight to compare strategies. In addition, we represented in Figures 12 and 13 respectively the Sharpe ratio and the delta ratio of the different allocation approaches.

If we compare allocation strategies that aim to minimise portfolio variance, as previously explained, the solution of the objective function worsens each time a constraint is added to the optimisation problem. The *GMV* portfolio always has the lowest risk compared to the *GMV constrained* portfolio and the *MV ESG* portfolio. As a result, the *MV ESG constrained* portfolio also has higher risk than the *GMV constrained* portfolio and the *MV ESG portfolio* which, respectively, do not impose an ESG portfolio score constraint and do not set maximum and minimum limits on the wealth invested in each company.

As shown in Figure 11, in terms of return, being a socially responsible investor who intended to minimise risk would have been controversial. In fact, while the *MV ESG portfolio* would result in a 0.54% higher annual average return than the *GMV* portfolio, the ESG constrained portfolio with a return equal to 6.61% would perform worse than the *GMV constrained* portfolio with a return equal to 6.90%. Nevertheless, looking at Figure 12, traditional strategies resulted in greater Sharpe ratios with respect to sustainable strategies due to the cost of higher annualized volatilities.

However, being socially responsible improve the portfolios ESG performance. The *MV ESG* portfolio has a higher ESG score of 18.87 points compared to the *GMV* portfolio. At the same time, investing in the *MV ESG constrained* portfolio would result in 13.82 points ESG performance improvement with respect to the *GMV constrained* portfolio. As a result, ESG leader portfolios have achieved considerably higher delta ratios than conventional portfolios, as reported in Figure 13.

If we compare allocation strategies which maximise the trade-off between return and risk, it can be seen that the traditional portfolios have performed better in terms of returns than the portfolio with environmental, social and governance constraint.

Being socially responsible for an investor by adopting this type of strategy would be more costly in terms of return when compared to the strategy that minimises variance. Investing in an ESG leader portfolio would mean to lose an average return of 3.25 percent per year by making a comparison between the *Maximum trade-off ESG* strategy with the specular conventional strategy and an average return of 2.54 percent per year implementing the *Maximum trade-off ESG constrained* strategy rather than the *Maximum trade-off constrained* strategy.

However, SRI portfolios highlighted a lower risk than traditional portfolios. Indeed, the average annual risk of the non-constrained ESG strategy is equal to 16.07%, 0.87% lower than the conventional non-constrained strategy which resulted a volatility equal to 16.94%. Similarly the average annual volatility of the constrained ESG strategy turned out to be equal to 16.33%, 0.23% less than the traditional constrained strategy with annual average risk of 16.62%. Although, traditional portfolios achieved higher Sharpe ratio with respect to ESG leader portfolio due to the larger differences in annual returns.
Expectedly, the *Maximum trade-off ESG* portfolio retained a higher ESG score of 17.6 points than *Maximum trade-off* portfolio which had an ESG score equal to 57.41. Equally, the sustainable constrained strategy performed an ESG score equal to 75.01, 17.12 point higher than the traditional constrained strategy which performed an ESG score equal to 57.89. For both SRI portfolios, higher ESG scores and lower volatilities resulted in higher delta ratios with respect to conventional portfolios.

Focusing on the maximum delta ratio allocation strategies, we can observe that portfolios which maximise the ESG score over the risk provided financial results similar to minimum variance ESG strategies. Indeed, both strategies did not consider the return in their optimisation problem; although they differ on whether to deal with ESG performance in the objective function (as Maximum delta ratio strategies) or in the constraint (as MV ESG strategies).

As we explained in the section 3.3.3 the maximum delta ratio strategy is inefficient within the mean-variance framework. Correspondingly, the results on the maximum delta ratio strategies reported worse financial performance than MV ESG strategies. The *Maximum delta ratio* portfolio earned, on average, 6.64% each year, 0.22 percent less than the annualized average return of the *Minimum Variance ESG* portfolio. Furthermore, the annualized volatility of the first portfolio is, on average, equal to 12.23%, 0.62 percent larger than the *Minimum Variance ESG* portfolio whose annualized volatility is equal to 11.61%. Likewise, the constrained strategy which maximise the delta ratio resulted in a lower return and higher volatility with respect to the *MV ESG constrained* portfolio. Consequently, Sharpe ratios of MV ESG strategies resulted higher than Sharpe ratios of maximum delta ratio strategies.

The ESG score of *Maximum delta ratio* portfolio is 79.44, 4.43 points higher than the *Minimum variance ESG* portfolio which achieved the minimum threshold to be consider ESG leader. Equally, the constrained portfolio that maximise the delta ratio obtained an ESG score of 77.57 higher than the ESG score of *Minimum Variance ESG constrained* portfolio equal to 75.01. Delta ratios of the maximum delta ratios strategies achieved higher outcomes with respect to the strategies that minimise the variance under a sustainability constraint. The results highlighted that maximum delta strategies are more sustainable than minimum variance ESG strategies.

Figure 11: Strategies' performance metrics

Figure 12: Strategies' Sharpe ratio

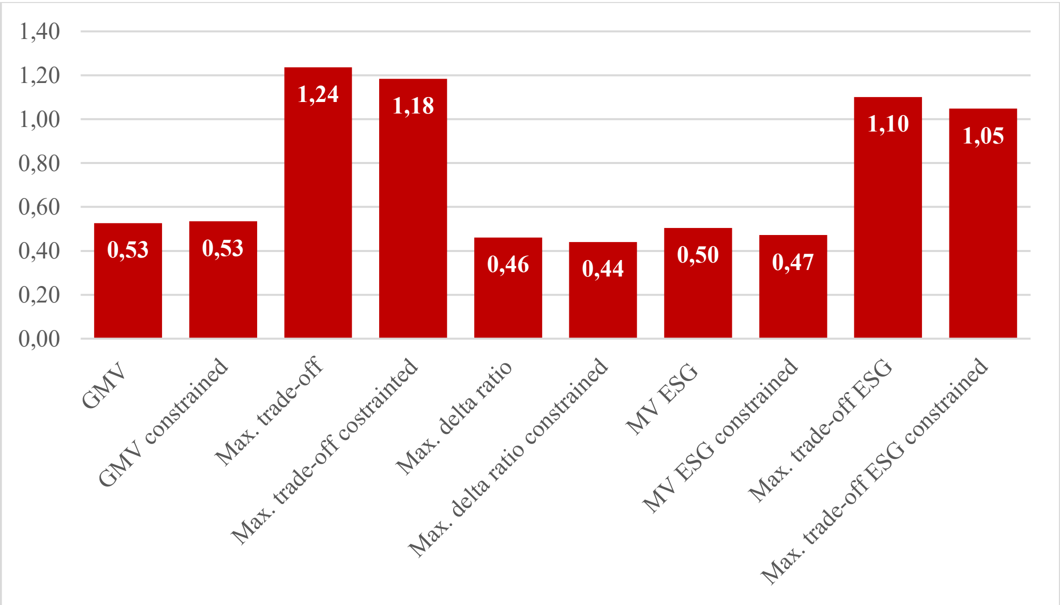
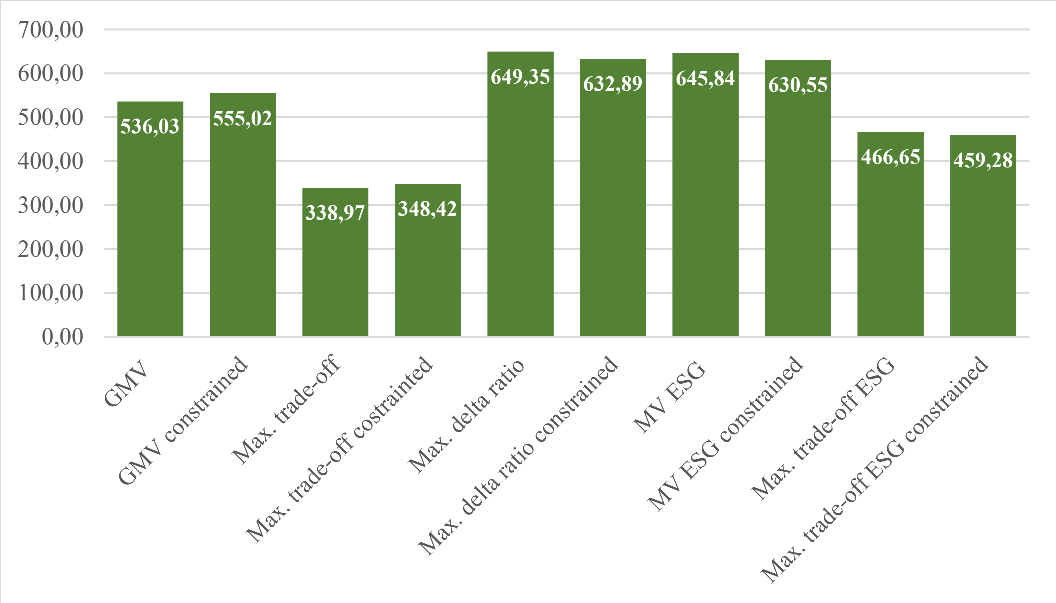


Figure 13: Strategies' delta ratio



3.4.2 Subsets

Using a smaller time window and a different number of companies, we performed the analysis on historical performances also on the eleven subsets in order to understand the evolution of the performance over time.

To sum up, each subset is composed by a different number of companies. The companies that constitute subset **1** were included in the Stoxx Europe 600 in 2010, the period used to calculate the historical mean and historical standard deviation is 5 years (from 2006 to 2010) of each company, the historical ESG score traced back to 2010.

A rolling window moving forward one year in each subset was used when computing the descriptive statistics and ESG scores. Accordingly, subset **11** is composed with companies included in the Stoxx Europe 600 in 2020, the descriptive statistics of the companies are computed with the historical price series from 2016 to 2020, and the historical ESG scores used date back to 2020.

Table 4 summarizes the results obtained in the eleven subsets implemented. In each subset, we reported the annualized historical mean, and the annualized historical volatility and the ESG score[17].

[17] Sharpe ratios and delta ratios of the eleven subsets are shown in the Table 5, as a comparison with the out-of-sample ratios, in Chapter 4.

Table 4: Summary results of strategies implemented in the eleven subsets

Subset	Strategy	Expected annualized return	Annualized volatility	ESG score
1	Stoxx Europe 600	-7,05%	26,06%	-
	Equally weighted	-4,20%	27,03%	56,79
	GMV	-1,89%	8,02%	51,74
	GMV *constrained*	-2,73%	8,84%	53,85
	Max. trade-off	22,99%	17,66%	43,51
	Max. trade-off *constrained*	20,82%	17,73%	37,98
	Max. delta ratio	-2,86%	8,86%	67,17
	Max. delta ratio *constrained*	-3,76%	9,72%	67,88
	Min. Variance ESG	-2,28%	10,38%	75,01
	Min. Variance ESG *constrained*	-3,71%	11,47%	75,09
	Max. trade-off ESG	20,26%	18,56%	75,01
	Max. trade-off ESG *constrained*	13,57%	17,71%	75,01
2	Stoxx Europe 600	-8,05%	25,36%	-
	Equally weighted	-6,70%	26,69%	57,01
	GMV	-3,71%	8,61%	49,97
	GMV *constrained*	-4,71%	9,58%	51,89
	Max. trade-off	16,90%	14,99%	39,88
	Max. trade-off *constrained*	15,28%	15,18%	40,74
	Max. delta ratio	-4,56%	9,97%	71,28
	Max. delta ratio *constrained*	-5,14%	10,57%	71,48
	Min. Variance ESG	-4,55%	10,59%	75,08
	Min. Variance ESG *constrained*	-5,69%	11,25%	75,06
	Max. trade-off ESG	14,21%	17,14%	75,04
	Max. trade-off ESG *constrained*	12,95%	17,45%	75,01
3	Stoxx Europe 600	-4,66%	25,21%	-
	Equally weighted	-1,21%	26,32%	57,30
	GMV	-0,96%	7,68%	44,36
	GMV *constrained*	-1,55%	8,63%	47,35
	Max. trade-off	20,63%	14,28%	38,54
	Max. trade-off *constrained*	20,23%	15,66%	41,45
	Max. delta ratio	-1,41%	9,22%	63,63
	Max. delta ratio *constrained*	-2,02%	9,84%	63,59
	Min. Variance ESG	-0,95%	11,46%	75,01
	Min. Variance ESG *constrained*	-1,72%	12,60%	75,01
	Max. trade-off ESG	19,49%	17,65%	75,01
	Max. trade-off ESG *constrained*	16,77%	18,03%	75,01

4	Stoxx Europe 600	9,43%	18,79%	-
	Equally weighted	14,54%	20,29%	57,92
	GMV	5,46%	7,60%	47,41
	GMV *constrained*	5,68%	7,94%	47,73
	Max. trade-off	33,44%	12,04%	34,70
	Max. trade-off *constrained*	32,82%	12,40%	35,57
	Max. delta ratio	5,23%	9,07%	75,26
	Max. delta ratio *constrained*	5,17%	9,27%	73,77
	Min. Variance ESG	5,19%	9,03%	75,01
	Min. Variance ESG *constrained*	5,43%	9,46%	75,12
	Max. trade-off ESG	26,78%	13,53%	75,01
	Max. trade-off ESG *constrained*	25,32%	14,03%	75,01
5	Stoxx Europe 600	6,07%	16,62%	-
	Equally weighted portfolio	8,54%	17,24%	58,75
	GMV	6,85%	7,93%	50,39
	GMV *constrained*	6,79%	8,29%	50,81
	Max. trade-off	27,95%	11,60%	41,11
	Max. trade-off *constrained*	26,57%	11,70%	40,63
	Max. delta ratio	5,76%	9,43%	77,67
	Max. delta ratio *constrained*	5,65%	9,62%	76,74
	Min. Variance ESG	5,69%	9,13%	75,01
	Min. Variance ESG *constrained*	5,57%	9,43%	75,06
	Max. trade-off ESG	22,61%	12,40%	75,01
	Max. trade-off ESG *constrained*	21,02%	12,54%	75,03
6	Stoxx Europe 600	5,32%	16,48%	-
	Equally weighted	8,36%	17,05%	60,56
	GMV	8,68%	8,46%	50,73
	GMV *constrained*	8,48%	8,74%	51,29
	Max. trade-off	30,67%	11,67%	46,79
	Max. trade-off *constrained*	29,44%	11,76%	47,94
	Max. delta ratio	9,29%	10,21%	79,40
	Max. delta ratio *constrained*	9,35%	10,34%	77,80
	Min. Variance ESG	9,18%	9,72%	75,01
	Min. Variance ESG *constrained*	9,23%	10,01%	75,04
	Max. trade-off ESG	25,19%	12,69%	75,01
	Max. trade-off ESG *constrained*	22,84%	12,58%	75,02
7	Stoxx Europe 600	7,57%	15,13%	-
	Equally weighted	12,32%	15,21%	62,45
	GMV	11,96%	8,69%	49,12
	GMV *constrained*	12,07%	8,89%	49,34
	Max. trade-off	37,15%	13,43%	43,34

	Max. trade-off *constrained*	35,37%	13,18%	43,57
	Max. delta ratio	10,54%	10,22%	78,05
	Max. delta ratio *constrained*	10,48%	10,43%	76,58
	Min. Variance ESG	10,55%	9,86%	75,04
	Min. Variance ESG *constrained*	10,57%	10,24%	75,04
	Max. trade-off ESG	32,06%	15,05%	75,01
	Max. trade-off ESG *constrained*	29,72%	14,55%	75,01
8	Stoxx Europe 600	6,03%	14,20%	-
	Equally weighted	10,29%	14,02%	64,92
	GMV	12,48%	8,42%	53,52
	GMV *constrained*	12,53%	8,59%	53,80
	Max. trade-off	30,32%	11,07%	52,96
	Max. trade-off *constrained*	29,67%	11,18%	53,43
	Max. delta ratio	10,52%	9,63%	76,52
	Max. delta ratio *constrained*	10,30%	9,77%	75,77
	Min. Variance ESG	10,73%	9,46%	75,06
	Min. Variance ESG *constrained*	10,37%	9,69%	75,07
	Max. trade-off ESG	29,36%	13,59%	75,01
	Max. trade-off ESG *constrained*	28,66%	13,81%	75,01
9	Stoxx Europe 600	0,52%	14,58%	-
	Equally weighted	3,84%	14,31%	66,84
	GMV	5,37%	8,89%	48,22
	GMV *constrained*	4,92%	9,12%	50,87
	Max. trade-off	31,90%	15,90%	52,97
	Max. trade-off *constrained*	30,21%	15,61%	52,28
	Max. delta ratio	4,07%	10,24%	83,55
	Max. delta ratio *constrained*	3,87%	10,45%	82,13
	Min. Variance ESG	3,97%	9,59%	75,07
	Min. Variance ESG *constrained*	3,94%	9,94%	75,02
	Max. trade-off ESG	26,23%	14,97%	75,01
	Max. trade-off ESG *constrained*	23,90%	14,52%	75,01
10	Stoxx Europe 600	4,14%	14,01%	-
	Equally weighted	7,73%	13,76%	68,58
	GMV	8,30%	8,43%	55,67
	GMV *constrained*	8,37%	8,62%	56,96
	Max. trade-off	36,51%	13,39%	56,60
	Max. trade-off *constrained*	35,21%	13,33%	57,13
	Max. delta ratio	6,11%	9,41%	81,86
	Max. delta ratio *constrained*	6,65%	9,56%	80,77
	Min. Variance ESG	6,57%	8,89%	75,11
	Min. Variance ESG *constrained*	6,81%	9,05%	75,01
	Max. trade-off ESG	31,30%	12,84%	75,02
	Max. trade-off ESG *constrained*	29,10%	12,49%	75,02

11	Stoxx Europe 600	1,58%	18,32%	-
	Equally weighted	5,53%	19,93%	68,67
	GMV	3,16%	10,31%	62,22
	GMV *constrained*	3,15%	10,69%	65,11
	Max. trade-off	43,49%	20,77%	57,15
	Max. trade-off *constrained*	40,28%	20,07%	57,94
	Max. delta ratio	3,97%	11,75%	82,89
	Max. delta ratio *constrained*	4,49%	12,01%	81,57
	Min. Variance ESG	3,48%	10,89%	75,01
	Min. Variance ESG *constrained*	4,16%	11,39%	75,05
	Max. trade-off ESG	32,43%	17,79%	75,01
	Max. trade-off ESG *constrained*	30,54%	17,79%	75,01

The results provided in Table 4 indicate that incorporating in our analysis ESG scores prior to 2020 portfolios performed worse, in sustainability terms, than portfolios in dataset 0. In some subsets, traditional portfolios could be classified as ESG loungers because they achieved ESG scores of less than 50. The strategies that performed the worst in terms of ESG performance were *Maximum trade-off* and *Maximum trade-off constrained* which had the lowest portfolio ESG scores in nine of the eleven subsets created. However, it can be easily noticed that even in the traditional allocation strategies portfolio ESG scores increased globally each time more recent ESG score data were employed.
In fact, looking at the equally weighted portfolio in each subset, it can be observed the gradual increasing of the ESG score. Indeed, the data show that the ESG score of the equally weighted portfolio grew from 56.79 in subset **1** to 68.67 in subset **11**. This is an indicator that highly capitalized companies have invested over time in ESG practices and enhanced their Corporate Social Responsibility, due in particular to regulations that have been issued in recent years.

Overall, the strategy that achieved the lowest annualized standard deviation is *GMV* portfolio in subset **4**, where portfolio risk is equal to 7.60%. On the other hand, the strategy that reached the highest annualized return is *Maximum trade-off* portfolio in subset **11**, with an average annualized return of 43.49%. While the portfolio that accomplished the highest ESG score is the *Maximum delta ratio* strategy in subset **9**, which measure an environmental, social and governance performance equal to 83.55.

Examining allocation strategies whose objective function is to minimise variance, as opposed to the results obtained in dataset 0, in most subsets, investing in the conventional portfolios would have generated a higher return than in the sustainable portfolios.

Subset **8** shows the greatest difference in returns between the traditional portfolios and the ESG portfolios. As a matter of fact, investing in the *MV ESG* portfolio would result in a 1.76% lower annual average return than the *GMV* portfolio, however improving the portfolio ESG score of a 21.53-point. At the same time, investing in the *MV ESG constrained* portfolio would result in 2.16% lower annual average return than the *GMV constrained* portfolio against a portfolio ESG performance improvement of 21.27 points.
Nevertheless, adopting a portfolio that would substantially improve sustainable performance did not always hurt financial returns. Subset **6** revealed that having invested in the *MV ESG* portfolio would have provided the investor with higher average annual return of 0.50% compared to the *GMV* portfolio. Equally, the *MV ESG constrained* portfolio gained annually on average 0.75% more than the *GMV constrained* portfolio. Similarly, subset **11** also showed better returns from ESG strategies than traditional strategies.

Considering the allocation strategies which maximise return-to-risk ratio, we can see that in every subset the traditional portfolios have performed better in terms of returns than the SRI portfolios. ESG leader strategies show a lower annual average risk than conventional strategies solely in the last three subsets.
Subset **6** presents the smallest difference in returns between implementing traditional versus socially responsible strategies. Investing by employing the *Maximum trade-off ESG* strategy, each year, would yield an average of 0.96 percent less compared to the traditional *Maximum trade-off* strategy. Likewise, the constrained ESG maximising return-to-risk strategy would have, on average, a 1.01% lower return per year than the traditional constrained return-to-risk strategy.
Conversely, results in the subset **11** reveal the largest difference in returns between traditional portfolios and sustainable portfolios. Investing in the *Maximum trade-off ESG* portfolio *would* pay a lower average return of 11.06% each year with respect to the *Maximum trade-off* portfolio. Comparably, investing in the *Maximum trade-off ESG constrained* portfolio would result in poorer annual return by, on average, 9.75% compared to the *Maximum trade-off constrained* portfolio. Although, focusing on volatilities, as in the subset **9** and **10**, ESG strategies turn out to be less risky than traditional strategies. As a result, the *Maximum trade-off* portfolio annualized volatility is on average 20.77% versus 17.79% of the annualized volatility of the *Maximum trade-off ESG* portfolio, and the *Maximum trade-off constrained* portfolio annualized volatility tests 20.07% against 17.79% of the annualized volatility of the *Maximum trade-off ESG constrained* portfolio. Certainly, non-constrained and constrained

ESG strategies have attained a grater ESG score than the mirrored traditional strategies, resulting respectively in a higher sustainability value of 17.86 and 17.07 points.

Analysing maximum delta ratio strategies in each subset, we can see that the portfolios ESG score have a steady increase over time. In fact, in subsets **1**, **2** and **3** the portfolios cannot be defined as ESG leader since their ESG score resulted lower than the minimum threshold equal 75.01. While, on the contrary, the latest three subsets resulted in portfolio ESG scores greater than 80 which represent the best sustainability performance among the all the SRI portfolios. Comparing the Maximum delta portfolios with MV ESG portfolios, it can be noticed that financial and non-financial metrics varied over time. In the first three subsets, the maximum delta ratios strategies resulted in a lower annual risk and lower annual return with respect to the MV ESG strategies. In subset **4**, the *Maximum delta ratio* portfolio obtained a 0.04 percent higher average annualized return and risk compared to the *MV ESG* portfolio. On the contrary, the maximum delta ratio constrained strategy resulted in a 0.26 percent lower annualized return and a 0.19 percent lower annual volatility with respect to the MV ESG constrained strategy. From subset **5**, maximum delta ratio strategies exceed MV ESG strategies in terms of sustainability scores. Portfolios maximising the delta ratio proved to be riskier, while from the point of view of returns, the issue is controversial. In some subsets the MV ESG portfolios provided higher returns, in others, the highest return was achieved by the maximum delta ratio portfolios.

On aggregate, the historical results showed that being a socially responsible investor has a financial cost, which can be expressed in terms of return and/or in terms of risk. Our results are in line according to the research of the authors Adler and Kritzman (2008) who had implemented a Monte Carlo simulation on conventional and sustainable portfolios and estimated that being socially responsible cost on average between 0.17% to 2.4% per year in terms of return. However, subsets involving more recent data reveal that sustainable strategies may perform better than traditional strategies. To give an example, subset 11, which calculates descriptive statistics with time series from 2016 to 2020, shows that the returns of MV ESG strategies and Maximum delta ratio are greater than the returns of GMV strategies. In fact, more recent studies demonstrated that ESG performance is not a proper indicator of return or risk. According to Lindsey et al. (2021) and the other authors mentioned in Chapter 2, investors can adjust the optimal weights of their portfolios to improve ESG performance without sacrificing returns.

Chapter 4

Strategies backtesting

For the purpose of examining the validity and the strengthen of the strategies described in the previous chapter, we conducted a backtest on each of the eleven subsets created. As defined by Bailey et al. (2014) “a backtest is a historical simulation of an algorithmic investment strategy”. In particular, in order to backtest a specific strategy, it is necessary to classify two different types of samples: the in-sample period (also identified as “learning period”) and the out-of-sample period (also identified as “testing period”). The in-sample is the time series period which we employed to implement and optimise strategies and then to compute the descriptive statistics. The out-of-sample period is the time series period not included in the computation of the portfolio optimisations outcomes. It is the period in which we simulated the performance the portfolios would achieve if they were actually built.

4.1 In-sample versus out-of-sample performances

In order to perform the strategies backtest, we employed the eleven subsets described in Chapter 3. Each subset comprises a different number of companies and a 5 years’ time series period (in-sample period). The expected annualized return, the annualized volatility and the ESG score reported in Table 4 summarizes the descriptive statistics of the in-sample period. The out-of-sample returns of each strategy were calculated by multiplying the matrix of out-of-sample returns by the vector of optimal weights resulting from the in-sample optimisation.
Given the fact that any portfolio rebalancing has not been considered, the out-of-sample window of each subset has the same sample of companies as the in-sample window. So, portfolios are always composed by the same optimal weights assigned to the firms resulting from the in-sample window optimisation process. The time length of the out-of-sample window varies for each subset as it starts from the period immediately following the last week included in the in-sample window and ends on 31st December 2020, the date when the most recent ESG scores are available. To exemplify, subset **1** has an out-of-sample window of 10 years. As the subsets number increases, the time window decreases by one year until data for the out-of-sample window are no longer available, as for subset **11**.

In Table 5, we reported the in-sample Sharpe ratios, in-sample delta ratios, the out-of-sample Sharpe ratios, and the out-of-sample delta ratios for each of the eleven subsets[18]. Ratios referred to each strategy described in the previous chapter. The out-of-sample ESG scores attributed to each portfolio are the result of an average of the annual ESG scores that companies have been assigned with, from the year when the out-of-sample period starts to the end of 2020.

Table 5: Comparison between in-sample and out-of-sample ratios

Subset	Strategy	In-sample Sharpe ratio	In-sample delta ratio	Out-of-sample Sharpe ratio	Out-of-sample delta ratio
1	Stoxx Europe 600	-0,31	-	0,14	-
	Equally weighted	-0,19	210,09	0,29	335,70
	GMV	-0,36	645,30	-0,12	417,77
	GMV *constrained*	-0,42	608,88	-0,06	415,53
	Max. trade-off	1,24	246,33	0,25	279,89
	Max. trade-off *constrained*	1,12	214,19	0,12	281,08
	Max. delta ratio	-0,44	758,35	-0,11	443,63
	Max. delta ratio *constrained*	-0,49	698,64	-0,09	439,87
	Min. Variance ESG	-0,32	722,42	-0,06	470,62
	Min. Variance ESG *constrained*	-0,41	654,83	-0,07	464,80
	Max. trade-off ESG	1,04	404,21	0,40	433,33
	Max. trade-off ESG *constrained*	0,71	423,55	0,13	425,24
2	Stoxx Europe 600	-0,36	-	0,35	-
	Equally weighted	-0,29	213,64	0,44	350,18
	GMV	-0,55	580,58	-0,17	369,22
	GMV *constrained*	-0,60	541,88	-0,11	373,14
	Max. trade-off	1,06	265,97	0,23	322,19
	Max. trade-off *constrained*	0,94	268,45	0,21	335,07
	Max. delta ratio	-0,56	714,79	-0,15	430,46
	Max. delta ratio *constrained*	-0,58	676,17	-0,14	423,80
	Min. Variance ESG	-0,52	708,98	-0,14	441,85
	Min. Variance ESG *constrained*	-0,59	666,93	-0,13	434,33
	Max. trade-off ESG	0,77	437,93	0,37	485,71
	Max. trade-off ESG *constrained*	0,69	429,94	0,38	489,25
3	Stoxx Europe 600	-0,22	-	0,20	-
	Equally weighted	-0,08	217,72	0,35	347,87
	GMV	-0,26	577,33	0,03	372,89
	GMV *constrained*	-0,30	548,56	-0,02	364,47

[18] The table including out-of-sample average return, volatility, and ESG score is provided in Appendix 1.

	Max. trade-off	1,37	269,84	0,16	342,26
	Max. trade-off *constrained*	1,23	264,62	0,08	332,23
	Max. delta ratio	-0,26	690,00	-0,02	441,49
	Max. delta ratio *constrained*	-0,31	646,37	-0,04	411,31
	Min. Variance ESG	-0,17	654,49	0,01	467,26
	Min. Variance ESG *constrained*	-0,22	595,31	-0,03	441,38
	Max. trade-off ESG	1,05	425,05	0,62	513,71
	Max. trade-off ESG *constrained*	0,87	416,09	0,51	532,98
4	Stoxx Europe 600	0,45	-	0,19	-
	Equally weighted	0,67	285,42	0,25	339,30
	GMV	0,59	623,96	-0,30	368,00
	GMV *constrained*	0,59	601,22	-0,30	361,69
	Max. trade-off	2,69	288,21	-0,12	214,90
	Max. trade-off *constrained*	2,57	286,83	0,04	246,02
	Max. delta ratio	0,47	830,24	0,13	529,88
	Max. delta ratio *constrained*	0,45	795,60	0,12	515,09
	Min. Variance ESG	0,46	830,31	0,12	527,41
	Min. Variance ESG *constrained*	0,47	794,47	0,14	526,43
	Max. trade-off ESG	1,91	554,47	0,63	512,31
	Max. trade-off ESG *constrained*	1,73	534,75	0,55	489,28
5	Stoxx Europe 600	0,30	-	0,17	-
	Equally weighted	0,44	340,78	0,23	330,33
	GMV	0,74	635,81	-0,19	350,07
	GMV *constrained*	0,70	612,91	-0,18	346,14
	Max. trade-off	2,32	354,31	0,37	324,95
	Max. trade-off *constrained*	2,19	347,40	0,33	312,79
	Max. delta ratio	0,50	823,56	0,02	520,74
	Max. delta ratio *constrained*	0,48	797,60	0,004	510,76
	Min. Variance ESG	0,51	821,53	-0,02	498,49
	Min. Variance ESG *constrained*	0,48	796,02	-0,02	498,23
	Max. trade-off ESG	1,74	604,90	0,33	529,27
	Max. trade-off ESG *constrained*	1,60	598,51	0,21	505,94
6	Stoxx Europe 600	0,26	-	0,12	-
	Equally weighted	0,43	355,13	0,18	324,07
	GMV	0,91	599,53	-0,25	317,83
	GMV *constrained*	0,86	587,11	-0,24	320,58
	Max. trade-off	2,54	400,81	0,16	259,04
	Max. trade-off *constrained*	2,42	407,46	0,17	273,89
	Max. delta ratio	0,81	777,78	-0,08	489,79
	Max. delta ratio *constrained*	0,81	752,58	-0,14	460,11
	Min. Variance ESG	0,84	771,76	-0,13	459,40
	Min. Variance ESG *constrained*	0,82	749,30	-0,16	446,94
	Max. trade-off ESG	1,91	591,02	0,25	436,48

	Max. trade-off ESG *constrained*	1,74	596,38	0,23	444,51

7	Stoxx Europe 600	0,43	-	0,16	-
	Equally weighted	0,74	410,49	0,24	324,85
	GMV	1,26	565,10	0,33	356,56
	GMV *constrained*	1,24	554,80	0,32	353,29
	Max. trade-off	2,69	322,79	0,48	239,36
	Max. trade-off *constrained*	2,61	330,58	0,49	254,76
	Max. delta ratio	0,93	764,04	0,41	581,30
	Max. delta ratio *constrained*	0,91	734,32	0,29	550,08
	Min. Variance ESG	0,97	761,39	0,40	562,78
	Min. Variance ESG *constrained*	0,93	733,10	0,30	538,87
	Max. trade-off ESG	2,06	498,27	0,85	421,12
	Max. trade-off ESG *constrained*	1,97	515,45	0,84	424,05

8	Stoxx Europe 600	0,35	-	0,08	-
	Equally weighted	0,66	463,11	0,14	292,52
	GMV	1,36	635,95	0,25	289,35
	GMV *constrained*	1,34	626,12	0,25	288,14
	Max. trade-off	2,65	478,36	0,30	227,42
	Max. trade-off *constrained*	2,57	478,05	0,29	231,81
	Max. delta ratio	0,99	794,52	0,52	372,44
	Max. delta ratio *constrained*	0,95	775,36	0,51	329,02
	Min. Variance ESG	1,03	793,64	0,48	378,09
	Min. Variance ESG *constrained*	0,97	774,92	0,51	329,40
	Max. trade-off ESG	2,09	552,00	0,50	355,61
	Max. trade-off ESG *constrained*	2,00	543,07	0,47	343,06

9	Stoxx Europe 600	-0,03	-	0,43	-
	Equally weighted	0,20	466,96	0,50	260,00
	GMV	0,49	542,44	0,30	195,97
	GMV *constrained*	0,43	557,95	0,34	209,57
	Max. trade-off	1,94	333,16	0,18	183,80
	Max. trade-off *constrained*	1,87	334,90	0,19	171,12
	Max. delta ratio	0,30	816,08	0,57	262,86
	Max. delta ratio *constrained*	0,27	785,75	0,47	283,08
	Min. Variance ESG	0,31	782,60	0,51	250,52
	Min. Variance ESG *constrained*	0,30	754,79	0,51	271,72
	Max. trade-off ESG	1,69	501,09	0,41	308,95
	Max. trade-off ESG *constrained*	1,58	516,55	0,26	274,58

10	Stoxx Europe 600	0,22	-	-0,06	-
	Equally weighted	0,49	498,42	0,12	193,90
	GMV	0,87	660,11	0,31	191,81
	GMV *constrained*	0,85	660,44	0,26	194,78
	Max. trade-off	2,65	422,52	1,02	159,44

	Max. trade-off *constrained*	2,57	428,53	0,99	158,08
	Max. delta ratio	0,54	870,02	-0,09	312,11
	Max. delta ratio *constrained*	0,59	844,69	-0,06	296,32
	Min. Variance ESG	0,63	845,05	0,05	280,28
	Min. Variance ESG *constrained*	0,64	828,50	0,06	276,03
	Max. trade-off ESG	2,36	584,27	0,81	221,00
	Max. trade-off ESG *constrained*	2,25	600,60	0,83	227,97
11	Stoxx Europe 600	0,03	-	-	-
	Equally weighted	0,23	344,52	-	-
	GMV	0,21	603,71	-	-
	GMV *constrained*	0,20	608,96	-	-
	Max. trade-off	2,05	275,19	-	-
	Max. trade-off *constrained*	1,96	288,70	-	-
	Max. delta ratio	0,25	705,52	-	-
	Max. delta ratio *constrained*	0,29	679,18	-	-
	Min. Variance ESG	0,23	688,48	-	-
	Min. Variance ESG *constrained*	0,28	658,70	-	-
	Max. trade-off ESG	1,77	421,67	-	-
	Max. trade-off ESG *constrained*	1,66	421,69	-	-

A strategy can be considered effective and predictive of future performance when the backtest returns out-of-sample results comparable to the in-sample results. Harvey and Liu (2015) state that there is a statistical and an economic reason on the reduction in Sharpe Ratios compared to historical performance related to the researchers' data mining. In their paper, the authors proposed a model that can quantify the correct haircut of Sharpe ratios in order to evaluate the strategies.

As we expected, the results showed in Table 5 demonstrates significant differences between in-sample performance and out-of-sample performance. Overall, Sharpe ratios and delta ratios out-of-sample had a marked decrease due to substantially increase of the volatility performances with respect to the historical performances. The reason behind these results lied in the inaccuracy of the sample estimation. Sample estimation is not an appropriate method capable of making accurate predictions about future stock market performance. Indeed, as wrote by Mynbayeva et al. (2022) in their research on the Markowitz out-of-sample optimisation, it is well known that the Markowitz model works in theory but performs poorly in practice.

However, despite the differences between in-sample and out-of-sample results, we can make considerations about the performance of out-of-sample strategies and compare conventional strategies with sustainable strategies. Without considering the different lengths of the out-of-sample windows, we can determine that, on aggregate, out-of-sample ESG strategies performed better than traditional out-of-sample strategies.

As a result, comparing minimum variance strategies and maximum delta ratio strategies, the *GMV* portfolio achieved a higher Sharpe ratio exclusively in two subsets compared with the *Maximum Delta ratio* and *MV ESG* portfolios. The out-of-sample delta ratio, on the other hand, was not always achieved by the *Maximum delta ratio* portfolio but in four subsets the MV ESG strategy performed better.

Although, the GMV constrained portfolio achieved a higher Sharpe ratio in five subsets compared to the sustainable strategies, while the highest delta ratio was achieved by the *Maximum delta ratio constrained* portfolio in six subsets and the *MV ESG constrained* portfolio in four subsets.

Focusing on maximum trade-off strategies, we found that both ESG constrained and not constrained portfolios achieve a higher delta ratio than traditional strategies in all the subsets and a higher Sharpe ratio in eight subsets.

However, the descriptive statistics in Table 5 suggest that in some subsets the financial performances of the benchmarks in the out-of-sample period are better than the financial performances of optimisation strategies. In fact, the Sharpe ratios of the Stoxx Europe 600 and the equally weighted portfolio are higher with respect to certain strategies, in particular, with respect to GMV strategies. The strategy that seems to perform best is the Maximum trade-off ESG which obtained a higher Sharpe ratio with respect to the equally weighted portfolio in eight subsets.

4.2 Rebalanced portfolios

In light of the results obtained, we simulated portfolios for a time period from the 1st of January 2011 to the 31st of December 2021 for each strategy. The portfolios were created using the eleven subsets above-mentioned. The firms and optimal weights resulting from the optimisations of each subset were implemented for an out-of-sample period of the following year. Therefore, the optimal weights of each portfolio were built based on a 5-year rolling window approach and with companies that were included in the Stoxx Europe 600 over the years. Assuming total disinvestment and reinvestment of the accumulated wealth, each year the portfolios were rebalanced according to the results defined in every subset.

To explain further, the optimal weights of subset **1**, which incorporates companies included in the European index in 2010 and calculates the descriptive statistics on a history period from

2006 to 2010, were used for the returns of the year 2011. For the year 2012, the portfolio was rebalanced according to the optimal weights and the companies contained in subset **2**. Following this rolling approach, portfolios on year 2021 were composed by the companies and findings obtained from subset **11**.

Weekly portfolio returns were obtained by multiplying the matrices of out-of-sample returns by the column vector of optimal weights. In this case, the returns of company i were calculated using the formula $r_{i,t} = \frac{P_t - P_{t-1}}{P_{t-1}} = \frac{P_t}{P_{t-1}} - 1$.

The different strategies implemented were compared with the benchmarks Stoxx Europe 600 and the equally weighted portfolio. As in previous chapter, we highlighted the results, on the one hand, by comparing conventional variance minimisation strategies with socially responsible strategies and delta ratio maximisation strategies. While, on the other hand, comparing conventional trade-off maximisation strategies with sustainable strategies.

The Table 6 summarizes the financial performance metrics of the Stoxx Europe 600 and of the yearly rebalanced portfolios from 2011 to 2021. Given the absence of ESG performance data for the year 2021, we calculated the portfolio ESG scores with an average from 2011 to 2020.

Table 6: Financial metrics of yearly rebalanced portfolios

Strategy	Annualized average portfolio return	Annualized portfolio volatility	ESG score
Stoxx Europe 600	6,22%	16,68%	-
Equally weighted	7,70%	18,08%	62,88
GMV	2,10%	13,95%	52,73
GMV *constrained*	3,04%	14,09%	53,90
Max. trade-off	6,44%	18,10%	48,24
Max. trade-off *constrained*	6,67%	17,80%	48,36
Max. delta ratio	5,53%	15,67%	75,48
Max. delta ratio *constrained*	5,12%	16,59%	74,63
Min. Variance ESG	5,43%	15,40%	75,36
Min. Variance ESG *constrained*	5,90%	16,49%	75,23
Max. trade-off ESG	8,07%	17,03%	75,18
Max. trade-off ESG *constrained*	8,10%	16,76%	75,10

The results of the rebalanced portfolios indicate that on average GMV strategies are the least volatile strategies, even compared to sustainable strategies. However, the annualized returns of GMV strategies are lower when compared with *Minimum Variance ESG* and *Maximum delta ratio* portfolios.

Although all minimum variance and maximum delta ratio strategies resulted less risky than the Stoxx Europe 600 and the equally weighted portfolio, the benchmarks had significantly higher average annualized returns.

The Maximum delta ratio portfolio proved to be the portfolio with the highest average ESG score, while the Maximum trade-off portfolio is the portfolio with the lowest level of sustainability.

Maximum trade-off ESG portfolios turned out to be the portfolios that achieved the highest annualized returns. In addition, these sustainable strategies not only performed better than traditional strategies, but also showed to be less risky. Compared with the Stoxx Europe 600, both traditional and sustainable strategies had higher annualized returns. In contrast, when considering the equally weighted portfolio, exclusively Maximum trade-off ESG portfolios had higher annualized returns.

Focusing solely on returns and wanting to learn about the returns of the portfolios from 1st of January 2011 to 31st of December 2021, we calculated cumulative returns. The cumulative returns R_T are given by the formula:

$$R_T = [\prod_{i=t+1}^{T}(1 + r_i)] - 1,$$

where t is the weekly return of the portfolio.

Figure 14 shows the cumulative returns from 1st of January 2011 to 31st of December 2021 of the Stoxx Europe 600 and the rebalanced portfolios built with the *Equally weighted* strategy, the *GMV strategy*, the *GMV constrained* strategy, the *Maximum delta ratio* strategy, the *Maximum delta ratio constrained* strategy, the *MV ESG* strategy, and the *MV ESG constrained* strategy.

Cumulative returns confirm the results obtained from Table 6, in fact GMV strategies have been shown to realize the portfolios with the worst returns. As of 31st of December 2021 GMV portfolio earned 13.01%, while GMV constrained portfolio gained 25.02%. On the other hand, sustainable strategies performed better: the maximum delta ratio portfolio achieved a cumulative return of 60.74%, a result very similar to the MV ESG portfolio which earned a return of 59.56%. In contrast, the MV ESG constraint strategy performed 65.50%, 13.8 percent better than the Maximum delta ratio constraint strategy which performed 51.70%.

However, none of the optimisation strategies managed to perform better than the market. In fact, the Stoxx Europe 600 over the same period gained 69.41 percent while the equally weighted portfolio earned 94.19 percent.

Figure 14: Cumulative returns of benchmarks, minimum variance, and maximum delta ratio strategies

In Figure 15 we plotted the weekly cumulative returns of the Stoxx Europe 600, the *Equally weighted* portfolio, the *Maximum trade-off* portfolio, the *Maximum trade-off constrained* portfolio, the *Maximum trade-off ESG portfolio* and the *Maximum trade-off ESG constrained* portfolio.

Figure 15 shows that again SRI strategies have performed better than conventional strategies. As of 31st of December 2021, the Maximum trade-off portfolio earned 68.87%, while the

Maximum trade-off portfolio constrained gained the 74.34%. On the other hand, the equivalent SRI strategies achieved respectively 106.35% and 108.04%. Overall, three out of four maximum trade-off strategies performed better than the Stoxx Europe 600, whereas exclusively the Maximum trade-off ESG strategies have been capable to earn more than the Equally weighted portfolio.

Figure 15: Cumulative returns of benchmarks and maximum trade-off strategies

Our analysis does not provide a graphical representation of the optimal weights assumed by the companies included in the portfolios over time. It would have been impossible to clearly depict the evolution of weights between 2011 and 2021 because of the significantly high number of companies included in the portfolios. However, in order to show the yearly assets' portfolio movements, we computed the turnover index. The turnover index allows to comprehend the portion of assets bought and sold each year. It is calculated multiplying the transpose of a column vector composed by ones with the column vector composed by the absolute value of the difference between the weights associated with a specific company at time t and the percentage of wealth invested in that company at the time $t-1$ with, all divided by 2. If the weights among companies do not change over time, the turnover index is equal to 0. The formula for the computation of turnover index is given by $\mathbf{1}^{T} \frac{|\omega_t - \omega_{t-1}|}{2}$.

Figures 16, 17 and 18 show graphically the turnover index for each optimisation strategy implemented in our study.

Figure 16: Turnover index of variance minimisation portfolios

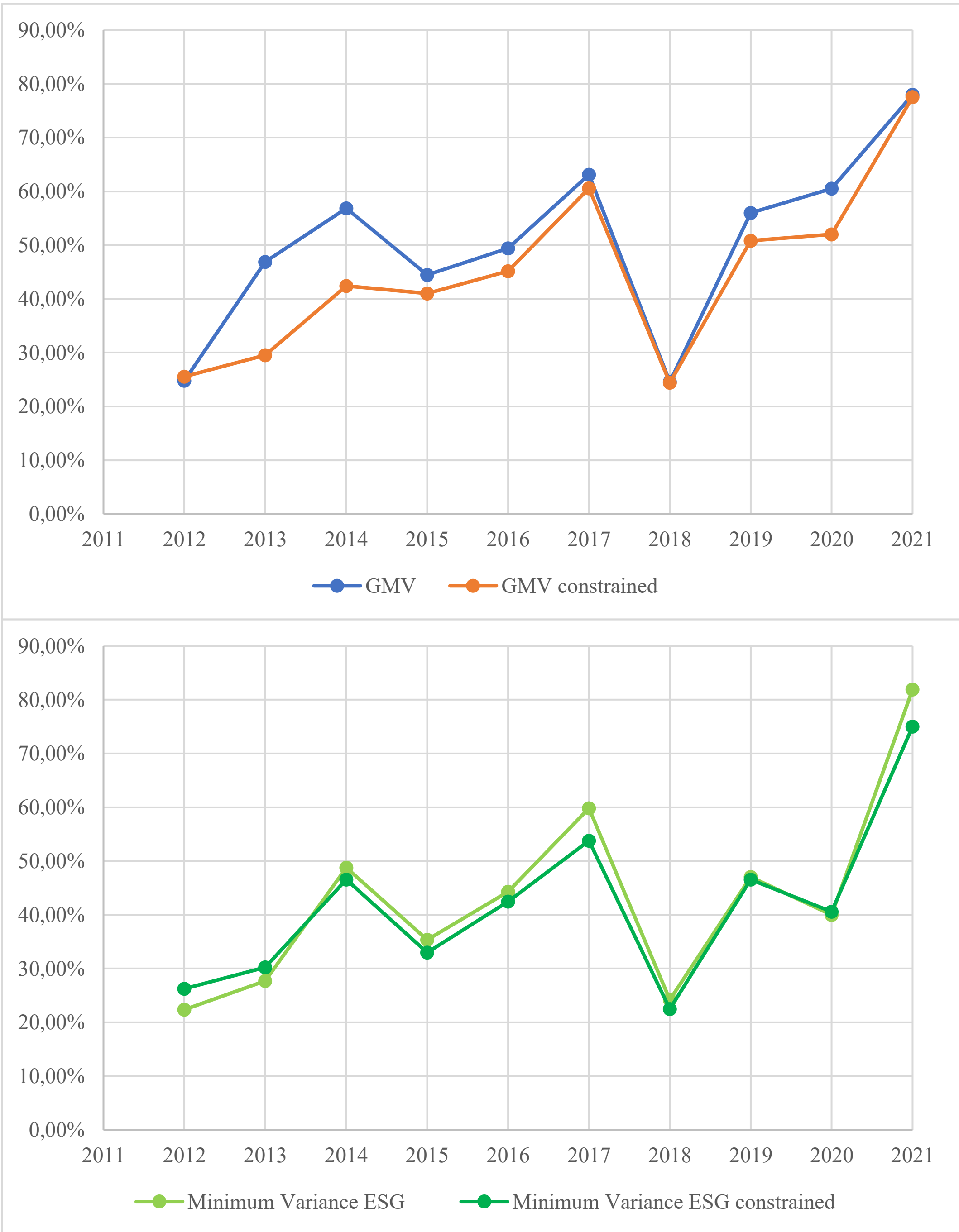


Figure 17: Turnover index of maximum trade-off portfolios

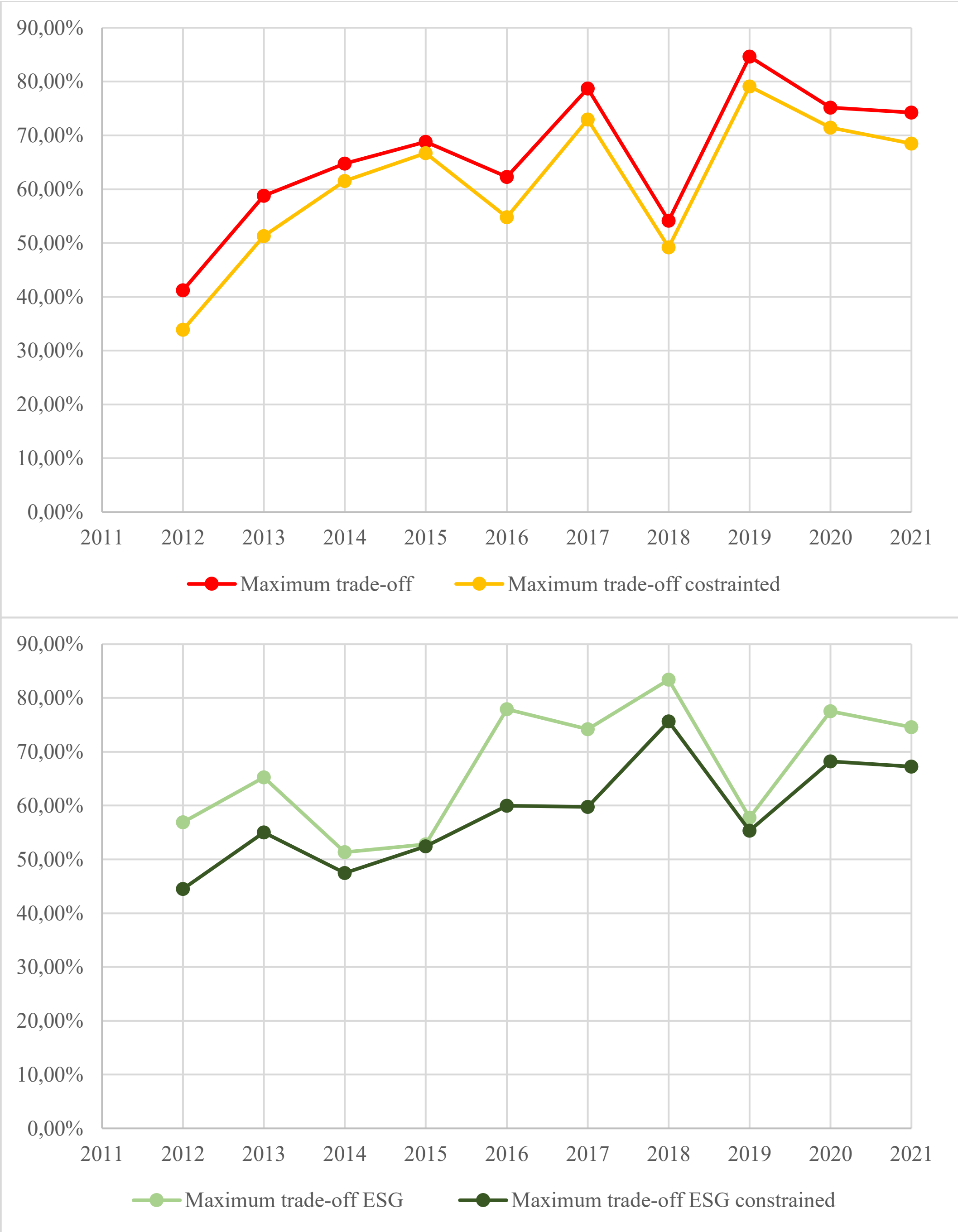
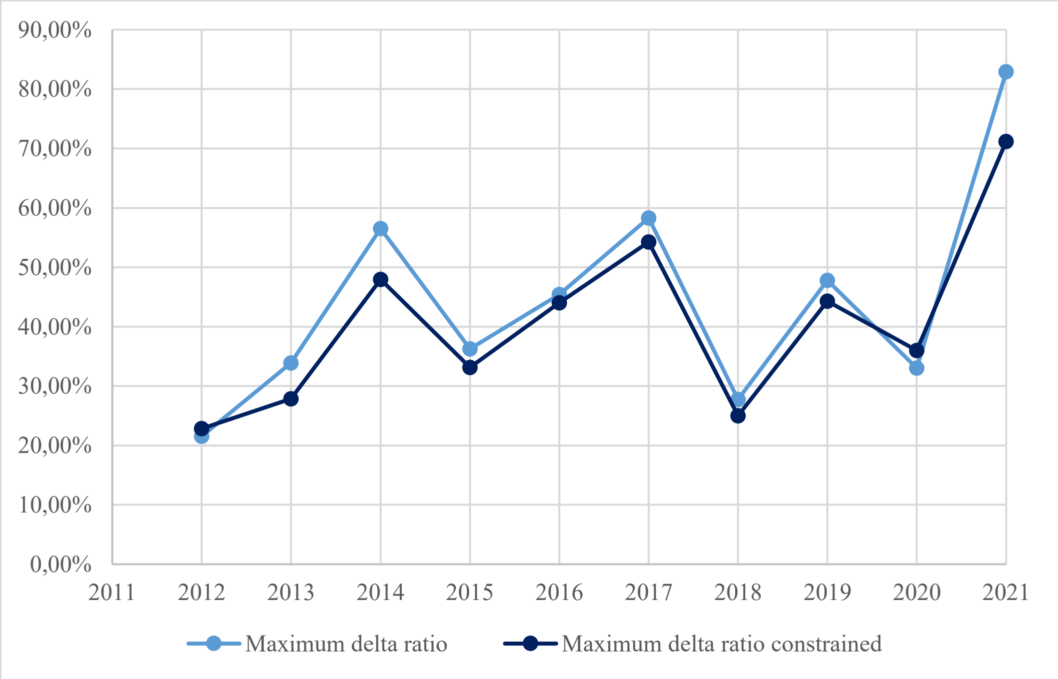


Figure 18: Turnover index of maximum delta ratio portfolios



Not surprisingly, the figures show high turnover index for each strategy. The reason depends on the significant number of different companies employed in our analysis in each year. The figures highlight that overall, due to the boundaries imposed, the turnover index of the constrained strategies is lower than index of the specular non-constrained strategies. On average, maximum trade-off strategies show a higher turnover index than other strategies. Moreover, sustainable strategies tend to have a lower turnover index with respect to traditional strategies. The higher turnover index over time was reached in 2019 by the Maximum trade-off portfolio with an 84.64% of asset bought or sold, while the lowest turnover index over time was achieved in 2012 by the GMV portfolio with 21.55% of asset bought or sold.

The findings achieved in this chapter allow us to draw some meaningful conclusions. We found evidence that the Markowitz model and its extensions in reality do not perform properly. The sample estimation does not have any predictive effects to consider valid the resulting allocation strategies. According to DeMiguel et al. (2009), the results obtained in our empirical analysis confirmed that a simple strategy such as Equally weighted portfolio outperformed other optimisation strategies in the out-of-sample period. As a result, exclusively Maximum trade-off ESG strategies performed better than the Equally weighted portfolio. In addition, also the benchmark Stoxx Europe 600 performed better than seven out of ten optimisation strategies.

However, we have provided evidence that overall, in the period between 2011 and 2021, socially responsible strategies outperformed conventional strategies corroborating the same conclusions as other studies in the literature. According to Drei et al. (2019), who studied the impact of ESG asset investing in the stock market, ESG investing in Europe outperformed other strategies between 2014 and 2019. Giese et al. (2019) identified a correlation between sustainable performance and corporate financial performance, suggesting that ESG scores are also good financial indicators. High environmental social and governance performance are indicators of healthy and competitive firms that safeguard themselves from risks such as pollution-related taxation or management fraud. In doing so, these companies reduce their systemic risk through lower cost of capital and higher valuation. In addition, according to Nofsinger and Varma (2014), sustainable strategies outperformed conventional strategies during crises, showing that highly ESG-rated firms have less exposure to tail risk. As a result, in our rebalanced portfolio cumulative returns of sustainable strategies are larger than the returns of traditional strategies during the covid pandemic crisis period[19]. In this period, while the GMV portfolio lost the 0.08%, the MV ESG portfolio and the Maximum delta ratio portfolio earned respectively the 0.70% and 6.35%. Similarly, while the GMV constrained portfolio yielded the 1.91%, the MV ESG constrained portfolio grew by the 2.13% and the Maximum delta ratio constrained earned the 5.14%. Even the maximum trade-off ESG strategies overperformed the traditional maximum trade-off strategies: the non-constrained ESG strategy gained the 24.79%, a 2.39% higher return than the non-constrained traditional strategy. The Maximum trade-off ESG constrained earned 29.32%, a 3.92% higher return than the Maximum trade-off ESG constrained strategy.

Eventually, our results demonstrated that high ESG scores are a signal of more efficient use of resources and human capital. These types of companies create higher profitability than their competitors. In line with these results, Giese et al. (2019) found that in the long run highly ESG-rated companies generate high returns which in turn imply high dividends for shareholders.

[19] We considered the covid pandemic crisis period from 21st of February 2020, the date in which first covid cluster has been disclosed in Europe, to the 31st of December, the last date available.

Conclusions

In this study, we conducted an analysis on Socially Responsible Investing in the European stock market considering companies included in the Stoxx Europe 600. The purpose of the paper is to highlight the performance differences between traditional and sustainable strategies. The traditional strategies implemented were simulated from the Markowitz model: the Global Minimum Variance strategy and the Maximum trade-off strategy. The sustainable strategies, on the other hand, are derived from an extension of the Markowitz model that includes each company's ESG score as a third criterion. The SRI strategies implemented are the Minimum Variance ESG, Maximum delta ratio, and Maximum trade-off ESG. While the Minimum Variance ESG and Maximum trade-off ESG strategies consider an ESG constraint in the optimisation problem, the Maximum delta ratio strategy maximises the ratio of ESG score to standard deviation in the objective function. Two different types of optimisation problems were implemented for each strategy: one that constrains the weights greater than or equal to zero and another that bounds the weights between 0.1 percent and 10 percent. Moreover, we implemented the equally weighted strategy as benchmark of the optimisation strategies.

The analysis on historical performance was conducted on different samples of companies. First, we calculated the historical performance of dataset 0, the sample that included fifteen years of weekly price time series of companies contained in the Stoxx Europe 600 in 2020 and calculates sustainability performance with 2020 ESG scores. Thereafter, we recreated different samples of companies: the subsets. Eleven subsets were created with the companies that composed the European index in a specific year. Each subset includes five years of weekly price time series of companies contained in the Stoxx Europe 600 between 2010 and 2020. The ESG score used to calculate sustainable performance in each subset dates to the year in which the sample of companies was included in the Stoxx Europe 600.

In addition, the subsets were also utilized to measure the out-of-sample performance of the different strategies implemented and to create a portfolio with annual rebalancing.

Computing historical performances on dataset 0, we obtained conflicting outcomes depending on whether the strategy is constrained or not. While the traditional non-constrained variance minimization strategy historically yielded on average less than the Minimum Variance ESG and Maximum delta ratio strategies, when analysing the constrained strategies, the GMV portfolio realized a better average historical return than the other two sustainable strategies. In

contrast, Maximum trade-off strategies, both non-constrained and constrained, outperformed Maximum trade-off ESG strategies, despite the latter experiencing lower volatilities.
The results obtained from the subsets confirmed that overall, historically traditional strategies performed better than sustainable strategies. While conventional Maximum trade-off strategies showed a higher average return in all the subset compared to Maximum trade-off ESG strategies, Minimum Variance ESG and Maximum delta ratio strategies realized higher returns in only two out of eleven subsets with respect to GMV strategies.
Overall, we observed that the ESG scores of optimisation strategies and equally weighted portfolio gradually increased each time we employed more recent data. These findings may be partly explained by the increasing companies' attention towards environmental social and governance issues.

Comparing the in-sample performance with the out-of-sample performance of the eleven subsets, we found that the Markowitz model and its extensions incorporating ESG performance are not predictive models. Interestingly, in contrast to in-sample results, sustainable strategies performed better than conventional ones in the out-of-sample analysis: the Minimum Variance ESG and Maximum delta ratio strategies outperformed the GMV portfolio in eight subsets. Focusing on the constrained strategies, the Maximum delta ratio constrained and MV ESG constrained strategies performed better in 5 subsets with respect to the GMV constrained. On the other hand, sustainable Maximum trade-off strategies achieved higher performance in eight subsets than traditional trade-off maximizing strategies.

The portfolios which are annually rebalanced according to the subsets' outcomes showed that sustainable portfolios outperformed traditional portfolios between 2011 and 2021. While the MV ESG portfolio achieved a 46.55% higher cumulative return compared to the GMV portfolio, the Maximum delta ratio portfolio realized a 47.73% higher return with respect to the traditional GMV portfolio which achieved a cumulative return equal to 13.01%. Similarly, the MV ESG constrained portfolio and the Maximum delta ratio constrained portfolio reached, respectively a 40.48% and a 25.68% greater return than the conventional GMV constrained portfolio that obtained a return equal to 25.02%. Equivalently, the Maximum trade-off ESG portfolio performed a 37.48% higher cumulative return compared to the traditional Maximum trade-off portfolio. While the Maximum trade-off ESG constrained portfolio realized a 33.7% greater cumulative return than the Maximum trade-off constrained portfolio which realized a return of 74.34%.
The outcomes obtained from the out-of-sample analysis reveal some meaningful considerations. We have demonstrated that being socially responsible does not necessarily

imply a cost in terms of financial performance; indeed, according to our analysis, sustainable strategies have outperformed traditional strategies over the past 10 years. In line with these findings, Khan et al. (2016) found that companies with high ESG ratings outperform companies with low ESG ratings, suggesting that ESG performance can be an indicator of companies' future performance. As shown in the study by Cheng et al. (2011), the greater financial performance of companies with a high level of corporate social responsibility can be explained by easier access to financial resources and a lower capital constraint. Moreover, Dhaliwal et al. (2011) show that companies with high disclosure of ESG information have a lower cost of equity capital. Moreover, as founded by Chen et al. (2021) and Nofsinger and Varma (2014), it seems that during crisis period sustainable strategies perform better than traditional strategies. In fact, during the pandemic covid crisis our yearly rebalanced SRI portfolios slightly outperformed the traditional portfolios.

Our analysis on companies' sustainability performance was conducted with Thompson Reuters ESG ratings. It is worth to mentioned that several rating agencies may evaluate the same company with different ESG scores. In fact, disagreement on ESG rating may lead to opposite implications in academic research. According to Gibson et al. (2021) who found a positive relationship between stock returns and ESG rating disagreement, asset managers aiming to implement sustainable strategies should consider the factor of ESG rating disagreement in their analysis. Therefore, the same study implemented with ESG scores from other rating agencies could lead to extremely different results.

Appendix 1

Table 7 shows the out-of-sample results of the eleven subsets. The results include the annualized average return, annualized average volatility and the average ESG score.

Table 7: Out-of-sample performances

Subset	Strategy	Out-of-sample annualized average return	Out-of-sample annualized volatility	Out-of-sample ESG score
1	Stoxx Europe 600	3,43%	17,40%	-
	Equally weighted	6,46%	18,99%	63,74
	GMV	-0,61%	13,74%	57,40
	GMV *constrained*	0,15%	14,49%	60,19
	Max. trade-off	5,72%	19,18%	53,69
	Max. trade-off *constrained*	3,21%	18,07%	50,80
	Max. delta ratio	-0,69%	15,37%	68,21
	Max. delta ratio *constrained*	-0,44%	15,60%	68,64
	Min. Variance ESG	0,09%	15,84%	74,56
	Min. Variance ESG *constrained*	-0,09%	15,94%	74,07
	Max. trade-off ESG	7,79%	17,19%	74,50
	Max. trade-off ESG *constrained*	3,31%	17,62%	74,91
2	Stoxx Europe 600	6,72%	16,40%	-
	Equally weighted	9,03%	18,21%	63,78
	GMV	-1,59%	15,25%	56,32
	GMV *constrained*	-0,68%	15,82%	59,02
	Max. trade-off	4,76%	16,14%	52,02
	Max. trade-off *constrained*	4,32%	15,85%	53,12
	Max. delta ratio	-1,46%	16,03%	69,01
	Max. delta ratio *constrained*	-1,23%	16,36%	69,33
	Min. Variance ESG	-1,34%	16,26%	71,85
	Min. Variance ESG *constrained*	-1,15%	16,57%	71,99
	Max. trade-off ESG	6,74%	15,43%	74,92
	Max. trade-off ESG *constrained*	6,74%	15,17%	74,24
3	Stoxx Europe 600	4,38%	17,09%	-
	Equally weighted	7,48%	18,46%	64,20
	GMV	1,40%	13,74%	51,25
	GMV *constrained*	0,66%	15,21%	55,45
	Max. trade-off	3,35%	15,00%	51,34
	Max. trade-off *constrained*	2,24%	15,75%	52,34
	Max. delta ratio	0,72%	15,15%	66,88
	Max. delta ratio *constrained*	0,36%	16,23%	66,76

	Min. Variance ESG	1,23%	16,13%	75,37
	Min. Variance ESG *constrained*	0,43%	17,07%	75,35
	Max. trade-off ESG	10,36%	15,07%	77,43
	Max. trade-off ESG *constrained*	8,45%	14,67%	78,18
4	Stoxx Europe 600	4,25%	17,32%	-
	Equally weighted	5,88%	19,19%	65,12
	GMV	-3,66%	15,65%	57,58
	GMV *constrained*	-3,78%	15,95%	57,70
	Max. trade-off	-1,50%	21,45%	46,10
	Max. trade-off *constrained*	1,70%	19,20%	47,23
	Max. delta ratio	2,81%	14,24%	75,48
	Max. delta ratio *constrained*	2,74%	14,47%	74,55
	Min. Variance ESG	2,78%	14,28%	75,29
	Min. Variance ESG *constrained*	2,98%	14,36%	75,59
	Max. trade-off ESG	10,41%	14,84%	76,03
	Max. trade-off ESG *constrained*	9,63%	15,77%	77,14
5	Stoxx Europe 600	3,97%	17,78%	-
	Equally weighted	5,58%	20,04%	66,21
	GMV	-2,16%	16,65%	58,30
	GMV *constrained*	-2,05%	16,87%	58,40
	Max. trade-off	7,26%	16,71%	54,29
	Max. trade-off *constrained*	6,85%	17,52%	54,80
	Max. delta ratio	1,35%	15,30%	79,67
	Max. delta ratio *constrained*	1,07%	15,46%	78,94
	Min. Variance ESG	0,67%	15,59%	77,71
	Min. Variance ESG *constrained*	0,76%	15,62%	77,82
	Max. trade-off ESG	6,00%	14,92%	78,96
	Max. trade-off ESG *constrained*	4,29%	15,68%	79,34
6	Stoxx Europe 600	3,20%	17,81%	-
	Equally weighted	4,79%	20,56%	66,63
	GMV	-3,47%	17,53%	55,73
	GMV *constrained*	-3,25%	17,56%	56,30
	Max. trade-off	4,27%	21,08%	54,61
	Max. trade-off *constrained*	4,46%	20,27%	55,52
	Max. delta ratio	-0,22%	16,15%	79,08
	Max. delta ratio *constrained*	-1,41%	16,78%	77,22
	Min. Variance ESG	-1,15%	16,47%	75,68
	Min. Variance ESG *constrained*	-1,68%	16,87%	75,40
	Max. trade-off ESG	5,33%	17,63%	76,94
	Max. trade-off ESG *constrained*	4,99%	17,10%	76,00
7	Stoxx Europe 600	3,96%	17,98%	-
	Equally weighted	6,06%	21,01%	68,26

	GMV	6,38%	16,55%	59,00
	GMV *constrained*	6,35%	16,74%	59,14
	Max. trade-off	12,35%	23,64%	56,59
	Max. trade-off *constrained*	11,76%	22,17%	56,49
	Max. delta ratio	6,80%	14,10%	81,97
	Max. delta ratio *constrained*	5,30%	14,62%	80,40
	Min. Variance ESG	6,73%	14,16%	79,67
	Min. Variance ESG *constrained*	5,44%	14,70%	79,23
	Max. trade-off ESG	16,68%	18,48%	77,83
	Max. trade-off ESG *constrained*	16,39%	18,35%	77,83
8	Stoxx Europe 600	2,72%	20,32%	-
	Equally weighted	4,23%	23,79%	69,59
	GMV	6,40%	21,57%	62,41
	GMV *constrained*	6,42%	21,72%	62,57
	Max. trade-off	9,12%	27,11%	61,64
	Max. trade-off *constrained*	8,78%	26,69%	61,87
	Max. delta ratio	12,30%	21,91%	81,61
	Max. delta ratio *constrained*	13,53%	24,50%	80,60
	Min. Variance ESG	11,29%	21,26%	80,39
	Min. Variance ESG *constrained*	13,40%	24,29%	80,02
	Max. trade-off ESG	12,03%	21,96%	78,10
	Max. trade-off ESG *constrained*	11,59%	22,72%	77,95
9	Stoxx Europe 600	10,93%	22,94%	-
	Equally weighted	14,32%	26,89%	69,92
	GMV	9,15%	26,97%	52,86
	GMV *constrained*	9,97%	26,34%	55,21
	Max. trade-off	6,78%	32,24%	59,26
	Max. trade-off *constrained*	7,43%	34,54%	59,10
	Max. delta ratio	19,19%	31,87%	83,78
	Max. delta ratio *constrained*	14,65%	29,17%	82,57
	Min. Variance ESG	16,75%	30,62%	76,71
	Min. Variance ESG *constrained*	15,37%	28,14%	76,46
	Max. trade-off ESG	11,08%	24,66%	76,18
	Max. trade-off ESG *constrained*	8,31%	28,06%	77,05
10	Stoxx Europe 600	-0,93%	30,71%	-
	Equally weighted	5,28%	36,39%	70,57
	GMV	9,31%	26,93%	51,65
	GMV *constrained*	8,20%	27,74%	54,03
	Max. trade-off	37,39%	35,59%	56,74
	Max. trade-off *constrained*	36,41%	35,66%	56,37
	Max. delta ratio	-1,40%	26,66%	83,21
	Max. delta ratio *constrained*	-0,57%	27,68%	82,02
	Min. Variance ESG	2,47%	27,17%	76,15

	Min. Variance ESG *constrained*	2,70%	27,48%	75,85
	Max. trade-off ESG	28,74%	34,12%	75,40
	Max. trade-off ESG *constrained*	28,55%	33,39%	76,11
11	Stoxx Europe 600	-	-	-
	Equally weighted	-	-	-
	GMV	-	-	-
	GMV *constrained*	-	-	-
	Max. trade-off	-	-	-
	Max. trade-off *constrained*	-	-	-
	Max. delta ratio	-	-	-
	Max. delta ratio *constrained*	-	-	-
	Min. Variance ESG	-	-	-
	Min. Variance ESG *constrained*	-	-	-
	Max. trade-off ESG	-	-	-
	Max. trade-off ESG *constrained*	-	-	-

Appendix 2

Below we reported the Matlab codes with which we implemented the different optimisation strategies.

```
% Global Minimum Variance portfolio optimisation with positive weights %

prob = optimproblem("Description","GMV Portfolio w>=0");
x = optimvar("x",526,"LowerBound",0);
S = transpose(x)*VCM*(x);
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
[sol,optval] = solve(prob);
optweights = sol.x;


% Global Minimum Variance constrained portfolio optimisation %

prob = optimproblem("Description","GMV Portfolio constrained");
x = optimvar("x",480,"UpperBound", 0.1,"LowerBound",0.0001);
S = transpose(x)*VCM*(x);
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
[sol,optval] = solve(prob);
optweights = sol.x;


% Maximum trade-off portfolio optimisation with positive weights %

prob = optimproblem("Description","Max trade-off Portfolio
w>=0","ObjectiveSense","maximize");
x = optimvar("x",471,"LowerBound",0);
S = (transpose(x)*R)/sqrt((transpose(x)*VCM*x));
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
initialGuess.x = one
[sol,optval] = solve(prob,initialGuess);
optweights = sol.x;


% Maximum trade-off constrained portfolio optimisation  %

prob = optimproblem("Description","Max trade-off Portfolio
constrained","ObjectiveSense","maximize");
x = optimvar("x",471,"LowerBound",0.0001,"UpperBound",0.1);
S = (transpose(x)*R)/sqrt((transpose(x)*VCM*x));
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
initialGuess.x = one
[sol,optval] = solve(prob,initialGuess);
optweights = sol.x;
```

```
% Maximum delta ratio portfolio optimisation with positive weights %

prob = optimproblem("Description","Max delta ratio Portfolio
w>=0","ObjectiveSense","maximize");
x = optimvar("x",526,"LowerBound",0);
S = (transpose(x)*ESG)/sqrt((transpose(x)*VCM*x));
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
initialGuess.x = one
[sol,optval] = solve(prob,initialGuess);
optweights = sol.x;


% Maximum delta ratio constrained portfolio optimisation %

prob = optimproblem("Description","Max delta ratio Portfolio
constrained","ObjectiveSense","maximize");
x = optimvar("x",526,"LowerBound",0.0001,"UpperBound",0.1);
S = (transpose(x)*ESG)/sqrt((transpose(x)*VCM*x));
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
initialGuess.x = one
[sol,optval] = solve(prob,initialGuess);
optweights = sol.x;


% Minimum Variance ESG portfolio optimisazion with positive weights and ESG constrained
%

prob = optimproblem("Description","MV ESG Portfolio w>=0");
x = optimvar("x",526,"LowerBound",0);
S = transpose(x)*VCM*(x);
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
prob.Constraints.ESG = transpose(x)*ESG >=  75.01
[sol,optval] = solve(prob);
optweights = sol.x;


% Minimum Variance ESG constrained portfolio optimisazion %

prob = optimproblem("Description","MV ESG Portfolio constrained");
x = optimvar("x",526,"LowerBound",0.0001,"UpperBound",0.1);
S = transpose(x)*VCM*(x);
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
prob.Constraints.ESG = transpose(x)*ESG >=  75.01
[sol,optval] = solve(prob);
optweights = sol.x;
```

```
% Maximum trade-off ESG portfolio optimisation with positive weights and ESG constrained
%

prob = optimproblem("Description","Max trade-off Portfolio
constrained","ObjectiveSense","maximize");
x = optimvar("x",471,"LowerBound",0);
S = (transpose(x)*R)/sqrt((transpose(x)*VCM*x));
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
initialGuess.x = one
prob.Constraints.ESG = transpose(x)*ESG >=  75.01
[sol,optval] = solve(prob,initialGuess);
optweights = sol.x;

% Maximum trade-off ESG constrained portfolio optimisation %

prob = optimproblem("Description","Max trade-off ESG Portfolio
constrained","ObjectiveSense","maximize");
x = optimvar("x",471,"LowerBound",0.0001,"UpperBound",0.1);
S = (transpose(x)*R)/sqrt((transpose(x)*VCM*x));
prob.Objective = S;
prob.Constraints.x = sum(x) ==  1.00;
initialGuess.x = one
prob.Constraints.ESG = transpose(x)*ESG >=  75.01
[sol,optval] = solve(prob,initialGuess);
optweights = sol.x;
```

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