



On ESG Portfolio Construction: A Multi-Objective Optimization Approach

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Abstract

Ahead of the new asset management era that calls for sustainable investments, the limitations of the traditional bi-objective mean–variance framework need to be resolved, to accommodate responsible investment objectives. In this paper, we propose a multi-objective minimax-based portfolio optimization model, attempting to simultaneously maximize the risk performance of the three typical ESG investment objectives. Also, apart from the systematic risk, the underlying formulation incorporates the controversy dimension, associated with each company participating in the optimal ESG portfolio. The validity of the proposed model is assessed through an extensive empirical testing on the EURO STOXX 50, the DAX, the CAC 40 and the DJIA, for a 5-year period. The results are considered as highly satisfactory, since the optimal ESG portfolios produced by the model provide consistently higher risk-adjusted returns, in comparison to their respective market benchmarks.

Keywords Portfolio selection · ESG investing · Multi-objective optimization

1 Introduction

A new generation of investors arrives with different takes on investing, reflecting rising awareness of environmental, social and governance (ESG) issues. Having reinforced extra-financial objectives, investors look for more sustainable and responsible investments. In this context, investors grant a higher importance to corporate social responsibility (CSR), which is “a concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with

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their stakeholders on a voluntary basis” (Commission of the European Communities, 2001).

Consequently, Sustainable and Responsible Investing (SRI) is currently experiencing a momentum. SRI is defined by Eurosif (2016) as “a long-term oriented investment approach, which integrates ESG factors in the research, analysis and selection process of securities within an investment portfolio, in order to better capture long term returns for investors, and to benefit society by influencing the behavior of companies”. The wide concept of SRI may be translated into several strategies (Eurosif, 2012): norms-based screens; best-in-class selection; sustainability themes; exclusions; ESG integration; engagement and voting; impact investing. As a tool for SRI, ESG ratings measure the risks related to the three extra-financial dimensions, namely the environmental, social and governance pillars. A complementary metric is the controversy level, measuring the level of involvement in controversial events impacting the environment or the society.

Nowadays, new generations of portfolio selection models originate from the traditional mean–variance framework (Markowitz, 1952) despite several criticisms—including its inability to incorporate additional criteria beyond expected return and variance (Aouni et al., 2018). The widespread use of purely financially oriented models overlooks investors’ satisfaction brought by ethical investing, by non-inclusion of self-realization needs (Maslow, 1943). Besides, investor sentiment influences companies’ commitment to corporate social responsibility (Naughton et al., 2019). It seems that the more investment decisions based on ESG risks, the higher the involvement of firms to sustainability. Thus, a significant spread of portfolio optimization models primarily based on ESG risk performance is likely to strengthen CSR activity under the impulse of investors. In parallel, stock price reacts to investments in CSR activities, which may encourage managers caring about their own firm’s stock price to strengthen their firm’s CSR (Friedman & Heinle, 2016).

Negative screening strategies are widespread within the SRI movement, allowing to exclude companies or industries that do not meet ESG investment criteria. Nonetheless, these exclusionary strategies seem to be inefficient, as both alpha and beta are negatively correlated to negative screenings’ intensity (Maveyraud & Jégourel, 2010). Additionally, Trinks and Scholtens (2017) suggest that opportunity costs are attached to negative screening strategies, due to their impact on the size of the investment universe and on risk-adjusted return performance. Meanwhile, Balllesteros et al. (2015) note that portfolio selection has been a traditional problem in multi-criteria decision making (MCDM) and observe a growing interest in including the SRI dimension in classical financial decision-making concerns. MCDM is a sub-discipline of operations research focused on problem solving with multiple conflicting objectives. More specifically, the problem covered by this paper falls under the scope of an MCDM sub-area called multiple objective linear programming (MOLP), as ESG investors have multiple conflicting objectives. More recently, Jacobsen et al. (2021) also indicate that it is a simple matter of using constrained optimization to achieve investment outcomes with sustainability goals or constraints. Thus, MCDM appears to be useful to tackle two issues in portfolio selection, namely the traditional mean–variance framework’s inability to incorporate investors’ sustainability objectives and the inefficiency of negative screening strategies. Following a MOLP-based

approach seems especially relevant in this case. However, we note a lack of multi-objective portfolio optimization models exclusively focused on ESG risks.

Considering the multiple objectives of SRI investors, our purpose in this paper is to develop a multi-objective minimax-based portfolio optimization model focused on ESG risks, attempting to maximize simultaneously the environmental, social, and governance risk performances, while applying a minimum threshold to the controversy performance. The proposed model includes customizable parameters to match investors' ESG preferences as well as their portfolio's constraints. The effectiveness of the proposed model is validated by an empirical testing application to European and American indices, i.e., the EURO STOXX 50, the CAC 40, the DAX, and the DJIA. Focusing on portfolio decarbonation, we attribute the highest importance to environmental risk performance in the empirical testing. Social risk performance comes in second in the defined priority order, then followed by governance risk performance.

Our contribution is firstly theoretical. Moving away from the traditional mean-variance framework, the proposed approach addresses the lack of multi-objective models exclusively focused on ESG risk performance. Our empirical testing results show a positive relation between ESG and financial performance, supporting the conclusions drawn by Friede et al. (2015) from their gathering of 2200 studies on ESG. Therefore, the proposed model can help to convincing a wider range of investors to shift towards SRI. In parallel, we also bring a managerial contribution with a unique solution to help investors in their decision making. In fact, the customizable features of the proposed model answer a key challenge: the diversity of ESG investors' profiles. As each ESG and controversy dimension is considered individually, the model allows to construct a portfolio in line with each investor's ESG priorities. Furthermore, it offers the possibility to control to some extent the portfolio exposure to controversial companies. Finally, the proposed model is a contribution for society as it supports the SRI movement to address rising ESG concerns. By contributing to spreading ESG-focused portfolio optimization models among investors, it reinforces companies' incentives to strengthen their CSR activity.

The rest of the paper proceeds as follows. In Sect. 2, we present the literature review. In Sect. 3, we present the proposed methodological framework, and we describe the theoretical modeling in Sect. 4. In Sect. 5, we provide an extensive analysis of the empirical results. Finally, we expose our conclusions in Sect. 6.

2 Literature Review

2.1 ESG Risks and Financial Performance

The SRI movement is heterogeneous (Sandberg et al., 2009). In fact, three types of investors invest in SRI mutual funds: profit-oriented investors, SR-oriented investors and investors valuing both financial performance and social responsibility (Nilsson, 2009). Despite expecting lower returns on SRI funds, socially responsible investors are ready to sacrifice financial performance to fulfill their social preferences (Riedl & Smeets, 2017). However, Oehmke and Opp (2020) suggest a complementarity

between socially responsible and financial investors, allowing them to jointly achieve higher surplus than either investor type alone.

More generally, Friede et al. (2015) regroup 2,200 studies on ESG and find that the large majority reports positive findings regarding the impact of ESG on corporate financial performance. Thus, ethical goals and objectives could be achieved without suffering from a financial backlash (Kempf & Osthoff, 2007; Basso & Funari, 2014). There can even be some reward in the form of lower idiosyncratic risk (Gouglar & Utz, 2020). Furthermore, as revealed by recent stock market crashes, SRI particularly differs from conventional investing during crises. Throughout the 2008–2009 financial crisis, firms with high CSR intensity experienced higher stock returns than firms with low CSR intensity (Lins et al., 2017) and SRI funds were more resilient to Lehman Brothers' bankruptcy (Nakai et al., 2016). Amid the COVID-19 pandemic, firms with higher environmental and social scores benefited from higher returns, lower volatility, and better operating profit margins (Albuquerque et al., 2020), and industry portfolio returns were significantly explained by ESG, driven by environmental and social pillars (Díaz et al., 2021). Meanwhile, Jacobsen et al. (2021) state that climate change will likely increase market volatility, all while decreasing equity returns and economic growth.

In fact, exposure to ESG risks materially increase portfolios' risks (Hübel & Scholz, 2020). These risks can be measured by ESG ratings (Champagne et al., 2021). Divergences in ESG ratings may occur, driven by variations in scope and measurement between raters (Berg et al., 2019) and reinforced in case of greater ESG disclosure (Christensen et al., 2021). However, Gibson et al. (2019) identified a positive correlation between stock returns and ESG rating disagreement driven by the environmental dimension, indicating a risk premium for companies facing stronger ESG rating disagreement. Specifically concerning SRI mutual funds, ESG scores assessing these funds lack of persistence due to changes in their holdings, thus requiring a portfolio rebalancing by SRI investors every two to three years.

2.2 Quantitative Portfolio Risk Management

Emphasizing on portfolio risk management, some new portfolio construction frameworks rely on clustering techniques. Providing less risky portfolios out of sample compared to traditional risk parity methods, the hierarchical risk parity approach (de Prado, 2016) also presents a better risk-adjusted performance than the equal risk contribution strategy (Jaeger et al., 2021). More recently, Ferretti (2022) introduces the naive network modularity-based allocation showing a generally good performance. However, these innovative methods lack integrating ESG risks.

Meanwhile, MCDM has been the ground of several models measuring the performance of socially responsible mutual funds. Based on data envelopment analysis (DEA), several models consider both financial and extra-financial performances (Basso & Funari, 2003, 2010; Galagedera, 2019; Pérez-Gladish et al., 2013), whereas other models are based on analytical hierarchy process (AHP) to assist

investors identifying socially responsible mutual funds matching their preferences (García-Melón et al., 2016; Pérez-Gladish & M'Zali, 2010).

MCDM also gathers a variety of portfolio selection models. Some of them include a social screening preceding the optimization process (Liagkouras et al., 2022; Liern et al., 2017). Others incorporate social responsibility within the optimization. Hallerbach et al. (2004) apply a multi-attribute approach to portfolio selection. Later, Ballesteros et al. (2012) introduce a financial-ethical bi-criteria stochastic model. In a three-step MCDM framework, Gupta et al. (2013) combine fuzzy-MCDM and AHP, respectively for financial evaluation and ethical performance. Gasser et al. (2017) enhance the traditional mean-variance framework by incorporation of social responsibility as third criterion, in addition to risk and return. Additionally, Chen et al. (2021) construct a three-stage framework evaluating social responsibility performance by means of DEA, selecting assets through a cross-efficiency analysis combining ESG scores and financial indicators, and incorporating risk, return and social responsibility performance within the portfolio optimization. García et al. (2019) develop a multi-objective portfolio selection approach considering each asset's return and ESG score as independent L-R power fuzzy variables. In order to integrate multiple investors' ESG preferences, Escrig-Olmedo et al. (2017) base their model on fuzzy TOPSIS MCDM. Calvo et al. (2015) also consider investors' preferences identified through a questionnaire, incorporating them as parameters of a utility function, targeting the most preferred balance between financial performance and social responsibility. As another decision support tool for investors, Lamata et al. (2018) propose a fuzzy-AHP-TOPSIS approach to rank firms based on their corporate social performance, overcoming the imprecise nature of the multi-dimensional concept that is corporate social responsibility. Clearly, sustainable portfolio selection models present a wide diversity under the scope of MCDM. However, the lack of multi-objective models exclusively focused on ESG risks is perceptible.

3 Proposed Framework

The proposed framework is based on a multi-objective minimax applied to extra-financial criteria, namely the ESG risk scores and the controversy level. These ratings are translated into performance via normalization, providing the environmental risk performance (ERP), the social risk performance (SRP), the governance risk performance (GRP) and the controversy performance (CP). In the proposed approach, the minimax allows to optimize each security's weight within the portfolio in order to minimize deviations from ESG targets (i.e., the maximum ERP, SRP and GRP achievable using available securities, while respecting identified hard constraints). Stemming from these three maximum objectives, the general objective of the proposed model can be synthesized as follows:

$$\text{MIN: } w_{ERP} \left(\frac{ERP_{MAX} - ERP_{MM}}{ERP_{MAX}} \right) + w_{SRP} \left(\frac{SRP_{MAX} - SRP_{MM}}{SRP_{MAX}} \right) \\ + w_{GRP} \left(\frac{GRP_{MAX} - GRP_{MM}}{GRP_{MAX}} \right) \quad (1)$$

where ERP_{MAX} is the target value of the portfolio's environmental risk performance, SRP_{MAX} is the target value of the portfolio's social risk performance, GRP_{MAX} is the target value of the portfolio's governance risk performance, ERP_{MM} is the actual value of the portfolio's environmental risk performance, SRP_{MM} is the actual value of the portfolio's social risk performance, GRP_{MM} is the actual value of the portfolio's governance risk performance, w_{ERP} is the weight attributed by the investor to the deviation of the portfolio from its target value concerning the environmental risk performance, w_{SRP} is the weight attributed by the investor to the deviation of the portfolio from its target value concerning the social risk performance, w_{GRP} is the weight attributed by the investor to the deviation of the portfolio from its target value concerning the governance risk performance, and w_{ERP} , w_{SRP} and w_{GRP} are positive constants.

Additionally, a minimum threshold is set for the portfolio's controversy performance, to control to some extent its exposure to controversial companies:

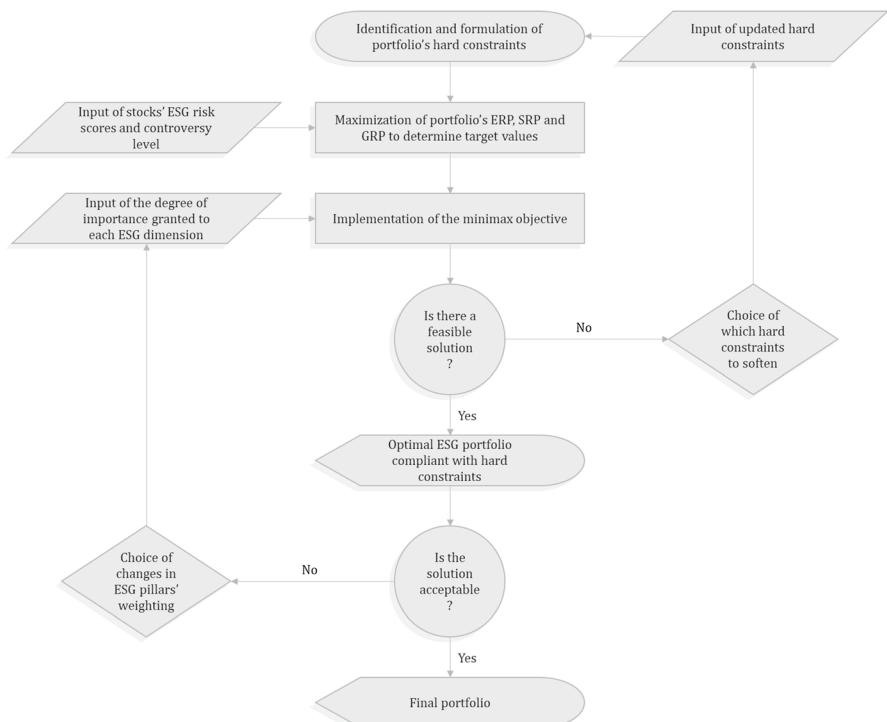


Fig. 1 Process flowchart of the proposed approach

$$CP_{MM} \geq CP^{LB} \quad (2)$$

where CP_{MM} is the actual value of the portfolio's controversy performance, and CP^{LB} is the lower bound applied to the portfolio's controversy performance.

Figure 1 maps the main steps when using the model. The first step is to identify the portfolio's hard constraints, and to formulate them as equations. In a second time, the stocks' ESG and controversy risk scores are inputted. The model maximizes the portfolio ERP, SRP and GRP to determine the three target values. Then, investors input their ESG preferences by weighting each dimension, allowing the implementation of the minimax objective. If the model is unable to output a feasible solution, hard constraints must be reviewed and softened by iteration. If there is a feasible solution, an optimal ESG portfolio compliant with the formulated hard constraints is produced by the model. Depending on the acceptance of the optimal ESG portfolio by the investor, changes may be required in the weighting of ESG dimensions by iteration.

4 Theoretical Modeling

In this section, we detail the technical elements of the applied theoretical modeling: (1) We explain the required preliminary data treatment, (2) We identify the decision variables and objectives, (3) We list the hard constraints to be applied, (4) We present the minimax objective.

4.1 Preliminary Data Treatment

The proposed model uses ESG risk scores and controversy level as inputs. Therefore, each firm considered in the optimization process must be rated regarding these matters. The treatment of these ratings consists of their normalization, expressed as follows:

$$\text{Performance} = \frac{X_i - X_{MIN}}{X_{MAX} - X_{MIN}} \quad (3)$$

where X_i is the rating of the security i , X_{MAX} is the maximum rating among the available securities, and X_{MIN} is the minimum rating among the available securities.

This data treatment must be done separately for environmental risk scores, social risk scores, governance risk scores and controversy levels. While high ESG risk scores and controversy level reflect a poor extra-financial performance, high ESG risk performances and controversy performance indicate a strong extra-financial performance.

4.2 Decision Variables and Objectives

We identify as continuous decision variable the weight of each security in the portfolio, such as:

$$w_i (1 \leq i \leq N) \quad (4)$$

where w_i is the weight of the security i , and N is the total number of securities in the portfolio.

The participation status of each security in the portfolio is considered as binary decision variable, defined as:

$$B_i \in \{0, 1\} \quad (5)$$

where B_i is the participation status of the security i , 0 means that the security i does not participate in the portfolio, and 1 means that the security i participates in the portfolio.

To build optimal ESG portfolios, we set three objectives to maximize, i.e., the risk performance of each ESG pillar, expressed as:

$$\text{MAX} : \sum_i w_i ERP_i \quad (6)$$

$$\text{MAX} : \sum_i w_i SRP_i \quad (7)$$

$$\text{MAX} : \sum_i w_i GRP_i \quad (8)$$

where ERP_i is the environmental risk performance of the security i , SRP_i is the social risk performance of the security i , and GRP_i is the governance risk performance of the security i .

4.3 Hard Constraints

Above the optimization process, we set several hard constraints to be faithfully applied to each portfolio built during the process, i.e., max ERP, max SRP, max GRP and minimax portfolios. Let:

- w^{LB} be the lower bound applied to the weights of all securities,
- w^{UB} be the upper bound applied to the weights of all securities,
- n^{LB} be the lower bound applied to the number of securities participating in the portfolio,
- n^{UB} be the upper bound applied to the number of securities participating in the portfolio,
- β_i be the beta of the security i ,
- β^{LB} be the lower bound applied to the portfolio's beta,
- β^{UB} be the upper bound applied to the portfolio's beta, and
- CP_i be the controversy performance of the security i .

Following the assumption that the investor solely takes long positions, security weights must be positive:

$$w_i \geq 0 \quad (9)$$

All the funds reserved for investment purpose must be invested in the available securities, which constrains the sum of their weights as follows:

$$\sum_i w_i = 1 \quad (10)$$

The number of securities participating to the portfolio is bounded by the investor:

$$\sum_i B_i \in [n^{LB}, n^{UB}] \quad (11)$$

The weight of each security participating in the portfolio must remain within the lower and upper bounds set by the investor, while the exclusion of a security from the portfolio must be reflected in a zero weight:

$$w_i - w^{LB}B_i \geq 0 \quad (12)$$

$$w_i - w^{UB}B_i \leq 0 \quad (13)$$

Additionally, the beta of the portfolio compared to the market must remain within the bounds set by the investor:

$$\sum_i w_i \beta_i \in [\beta^{LB}, \beta^{UB}] \quad (14)$$

Finally, the portfolio's controversy performance must comply with a lower bound set by the investor:

$$\sum_i w_i CP_i \geq CP^{LB} \quad (15)$$

4.4 Minimax Objective

From the objectives previously identified, the three target values of the portfolio are expressed as follows:

$$ERP_{MAX} = \text{MAX} : \sum_i w_i ERP_i \quad (16)$$

$$SRP_{MAX} = \text{MAX} : \sum_i w_i SRP_i \quad (17)$$

$$GRP_{MAX} = \text{MAX} : \sum_i w_i GRP_i \quad (18)$$

Then, the minimax objective is to minimize the sum of the portfolio's weighted deviations from the three target values, where the deviation from each target value is weighted according to the investor's preferences in terms of ESG concerns:

$$\begin{aligned} \text{MIN:}_{w_{ERP}} & \left(\frac{ERP_{MAX} - (\sum_i w_i \cdot ERP_i)}{ERP_{MAX}} \right) + w_{SRP} \left(\frac{SRP_{MAX} - (\sum_i w_i \cdot SRP_i)}{SRP_{MAX}} \right) \\ & + w_{GRP} \left(\frac{GRP_{MAX} - (\sum_i w_i \cdot GRP_i)}{GRP_{MAX}} \right) \end{aligned} \quad (19)$$

To implement the minimax objective, we establish a minimax variable Q to be minimized with the objective, expressed as follows:

$$\text{MIN} : Q \quad (20)$$

subject to the additional constraints:

$$w_{ERP} \left(\frac{ERP_{MAX} - (\sum_i w_i \cdot ERP_i)}{ERP_{MAX}} \right) \leq Q \quad (21)$$

$$w_{SRP} \left(\frac{SRP_{MAX} - (\sum_i w_i \cdot SRP_i)}{SRP_{MAX}} \right) \leq Q \quad (22)$$

$$w_{GRP} \left(\frac{GRP_{MAX} - (\sum_i w_i \cdot GRP_i)}{GRP_{MAX}} \right) \leq Q \quad (23)$$

and where deviations from the target values are limited by an upper bound, which is chosen by the investor:

$$\frac{ERP_{MAX} - (\sum_i w_i \cdot ERP_i)}{ERP_{MAX}} \leq \Delta^{UB} \quad (24)$$

$$\frac{SRP_{MAX} - (\sum_i w_i \cdot SRP_i)}{SRP_{MAX}} \leq \Delta^{UB} \quad (25)$$

$$\frac{GRP_{MAX} - (\sum_i w_i \cdot GRP_i)}{GRP_{MAX}} \leq \Delta^{UB} \quad (26)$$

where Δ^{UB} is the deviation's upper bound.

The weights w_{ERP} , w_{SRP} and w_{GRP} are customizable by the investor. The higher w_{ERP} , w_{SRP} or w_{GRP} , the higher the emphasis on the deviation from the

corresponding target value. As the minimax objective is to minimize Q, a higher weight thus represents a higher penalty applied to the deviation. Two specific cases are possible for the investor. In the first case, the investor has no preference in terms of ESG dimensions. Consequently, w_{ERP} , w_{SRP} and w_{GRP} should be equally weighted. An example of equal weighting could be $w_{ERP} = w_{SRP} = w_{GRP} = 5$. In the second case, the investor attributes unequal importance to the three ESG pillars. Therefore, different values should be set for w_{ERP} , w_{SRP} and w_{GRP} . The highest weight should be applied to the most important ESG dimension, while the lowest weight should be applied to the dimension that the investor is the more willing to forego. By descending order of importance, an example of unequal weighting could be $w_{ERP} = 15$, $w_{SRP} = 10$ and $w_{GRP} = 5$.

The deviation's upper bound Δ^{UB} is also customizable by the investor, helping to restrain the model from building portfolios with excessive deviations from the target values. By default, we set Δ^{UB} at 10%.

The proposed model offers a mean to find the best trade-off between the environmental, social and governance risk performances, considering the degree of importance set by the investor to each one of these objectives. Furthermore, it offers the possibility to control to some extent the portfolio exposure to controversial companies. The customizable dimensions of the proposed model answer a major challenge, which is the diversity of ESG investors' profiles.

5 Empirical Testing

5.1 Data, Horizon of the Analysis and Initial Discussion

In this section, we thoroughly explain the full grid of details concerning the modeling routine of the empirical testing procedure. Four indices have been selected for the empirical testing validation process to provide regionally diversified perspectives across European and American equity markets, i.e., the EURO STOXX 50, the CAC 40, the DAX and the DJIA. The EURO STOXX 50 is a free float market capitalization weighted index, reflecting the performance of the 50 largest blue-chip companies among Eurozone super-sectors. The CAC 40 is a French free float market capitalization weighted index, representing the performance of the 40 largest and most actively traded shares listed on Euronext Paris. The DAX is a German capitalization weighted index, illustrating the performance of the 30 largest and most actively traded German blue-chip companies listed on the Frankfurt Stock Exchange. The DJIA is an American price-weighted index, showing the performance of 30 major blue-chip companies listed on U.S. stock exchanges. The financial performance is assessed through a backtesting. This procedure presents its own limits. In fact, conditions might favor our portfolios over the benchmarks within the delimited time horizon, but we generally note a positive relation between ESG and financial performance in our literature review. Consequently, building ESG portfolios outperforming the market out of pure randomness seems less likely. Furthermore, the survivorship bias might impact the backtesting results, although our model focuses on

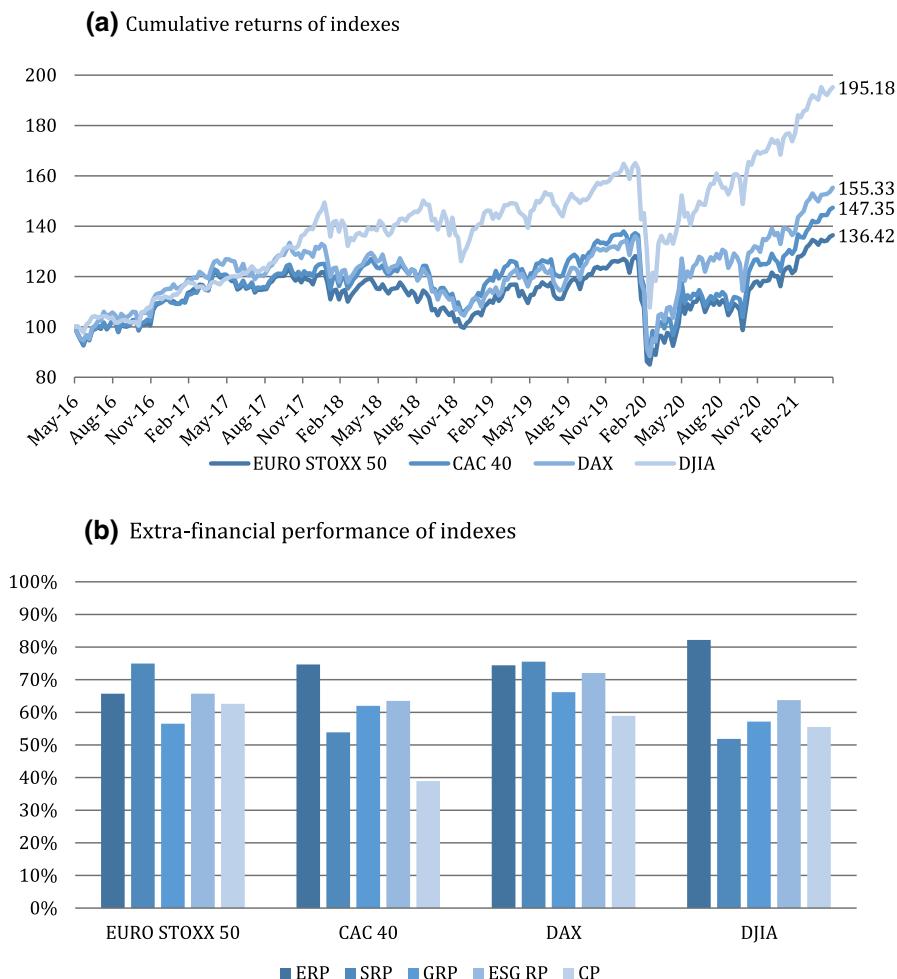


Fig. 2 **a** Cumulative returns of indexes. **b** Extra-financial performance of indexes. Note ERP-Environmental Risk Performance, SRP-Social Risk Performance, GRP-Governance Risk Performance, ESG RP-ESG Risk Performance and CP-Controversy Performance

investing in low-risk stocks. Besides, future market changes are not considered, even if they are difficult to forecast in any case.

Concerning the financial performance, Fig. 2a compares the cumulative returns (basis of 100 points) of each index over five years, i.e., from May 29th, 2016, to May 30th, 2021. The delimited time horizon consists of 262 weekly return observations, using data from Investing.com. The DAX mainly outperforms the other indexes until the second half of 2017. From the end of 2017, the strong performance of the DJIA starts to stand out from European indexes. This configuration is confirmed until the end of the considered time horizon. The CAC 40 mainly underperforms the DJIA and the DAX until early 2018. The CAC 40 progressively catches up with the DAX

Table 1 Extra-financial ratings of DJIA's components

No	Company	ERS	SRS	GRS	ESG RS	CL
1	3 M	12.8	14.0	8.4	35.2	3
2	American Express	0.1	9.9	9.8	19.8	3
3	Amgen	0.0	12.8	6.3	19.1	2
4	Apple	0.1	7.7	8.9	16.7	3
5	The Boeing Company	7.8	19.7	8.8	36.3	4
6	Caterpillar	10.7	19.6	8.9	39.2	4
7	Chevron	18.3	12.0	10.0	40.3	3
8	Cisco Systems	0.5	5.9	6.1	12.5	2
9	The Coca-Cola Company	9.2	10.8	5.1	25.1	3
10	Goldman Sachs	0.8	14.2	13.0	28.0	3
:	:	:	:	:	:	:
20	Nike	2.3	5.6	6.9	14.8	3
21	Procter & Gamble	8.2	9.5	7.4	25.1	3
22	salesforce.com	0.5	6.5	4.3	11.3	2
23	The Travelers Companies	1.5	9.3	11.1	21.9	2
24	UnitedHealth Group	0.0	15.4	5.9	21.3	3
25	Verizon Communications	1.7	10.2	6.2	18.1	3
26	Visa	0.1	9.8	7.4	17.3	3
27	Walmart	3.4	17.2	6.9	27.5	4
28	Walgreens Boots Alliance	1.9	10.9	4.7	17.5	3
29	The Walt Disney Company	0.0	8.1	8.1	16.2	2

ERS environmental risk score, SRS social risk score, GRS governance risk score, ESG RS ESG risk score and CL controversy level

during the first half of 2018 and outperforms the DAX between the second half of 2018 and April 2020. After that, the DAX beats again the CAC 40. Compared to the three previous indexes, the EURO STOXX 50 stands as a laggard across the entire time horizon. In fact, the 5-year total return of the EURO STOXX 50 solely amounts to 36.42%, while it reaches 47.35% for the CAC 40 and 55.33% for the DAX—all of them being strongly outperformed by the DJIA recording a 5-year total return of 95.18%.

Regarding the extra-financial performance, the raw data is provided by Sustainalytics and accessed via Yahoo Finance. For indicative purpose, Table 1 presents a sample of the raw data collected for the DJIA and Table 2 shows the same sample after normalization. Figure 2b provides a comparative view on the level of success resulting from the manner of each index to take advantage of its own best rated components in terms of ESG and controversy risks through its weight allocation. The DJIA records the highest ERP, followed by the CAC 40 and DAX and finally the EURO STOXX 50. Regarding the SRP, the DAX stands slightly ahead of the EURO STOXX 50, whereas the CAC 40 and the DJIA face a much weaker SRP. The DAX surpasses the CAC 40 in terms of GRP, while the DJIA and the EURO STOXX 50 obtain a lower GRP. Essentially, the DAX

Table 2 Extra-financial performance of DJIA's components

No	Company	ERP (%)	SRP (%)	GRP (%)	ESG RP (%)	CP (%)
1	3 M	30.05	38.67	49.46	39.39	50.00
2	American Express	99.45	66.00	34.41	66.62	50.00
3	Amgen	100.00	46.67	72.04	72.90	100.00
4	Apple	99.45	80.67	44.09	74.74	50.00
5	The Boeing Company	57.38	0.67	45.16	34.40	0.00
6	Caterpillar	41.53	1.33	44.09	28.98	0.00
7	Chevron	0.00	52.00	32.26	28.09	50.00
8	Cisco Systems	97.27	92.67	74.19	88.04	100.00
9	The Coca-Cola Company	49.73	60.00	84.95	64.89	50.00
10	Goldman Sachs	95.63	37.33	0.00	44.32	50.00
⋮	⋮	⋮	⋮	⋮	⋮	⋮
20	Nike	87.43	94.67	65.59	82.56	50.00
21	Procter & Gamble	55.19	68.67	60.22	61.36	50.00
22	salesforce.com	97.27	88.67	93.55	93.16	100.00
23	The Travelers Companies	91.80	70.00	20.43	60.74	100.00
24	UnitedHealth Group	100.00	29.33	76.34	68.56	50.00
25	Verizon Communications	90.71	64.00	73.12	75.94	50.00
26	Visa	99.45	66.67	60.22	75.45	50.00
27	Walmart	81.42	17.33	65.59	54.78	0.00
28	Walgreens Boots Alliance	89.62	59.33	89.25	79.40	50.00
29	The Walt Disney Company	100.00	78.00	52.69	76.90	100.00

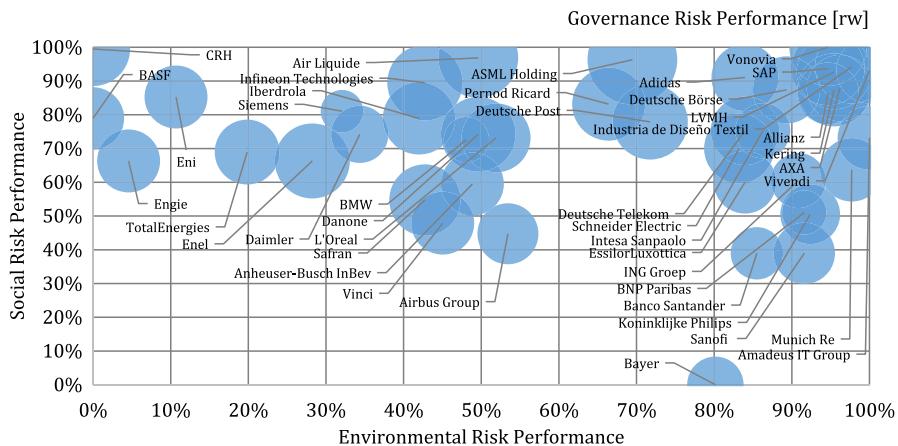
ERP environmental risk performance, SRP social risk performance, GRP governance risk performance, ESG RP ESG risk performance and CP controversy performance

shows the best ESG risk performance, followed by a grouping of the EURO STOXX 50, the DJIA and the CAC 40. Finally, the EURO STOXX 50 takes the lead in terms of CP, closely followed by the DAX and the DJIA, while the CAC 40 has the worst CP.

The main metrics employed to assess the financial and extra-financial performances of the proposed model are as follows: (a) As measure of volatility, the standard deviation of weekly returns, (b) As measures of return, the total return and the average weekly return, (c) As measure of risk-adjusted return, the Sharpe ratio obtained by dividing the average weekly return by the standard deviation of weekly returns, and (d) As measures of extra-financial performance, the novel ESG metrics that have been defined and introduced elaborately in Sects. 3 and 4.

Table 3 Selected values for the customizable parameters

No	Parameter	Selected value
1	n^{LB}	16
2	n^{UB}	22
3	w^{LB}	0.005
4	w^{UB}	0.080
5	β^{LB}	0.900
6	β^{UB}	1.100
7	CP^{LB}	0.600
8	Δ^{UB}	0.100
9	w_{ERP}	15
10	w_{SRP}	10
11	w_{GRP}	5

**Fig. 3** ESG risk performance of EURO STOXX 50's components**Table 4** Statistical indicators for extra-financial performance of EURO STOXX 50's components

No	Statistical indicator	ERP	SRP	GRP	ESG RP	CP
1	Minimum	0.00	0.00	0.00	0.00	0.18
2	Average	0.64	0.73	0.54	0.61	0.64
3	Median	0.76	0.75	0.53	0.75	0.64
4	Maximum	1.00	1.00	1.00	1.00	0.90
5	Standard deviation	0.32	0.20	0.17	0.23	0.16
6	Skewness	-0.67	-1.20	-0.43	-0.65	-0.45
7	Kurtosis	-0.80	2.44	1.74	0.51	0.10

ERP environmental risk performance, SRP social risk performance, GRP governance risk performance, ESG RP ESG risk performance and CP controversy performance

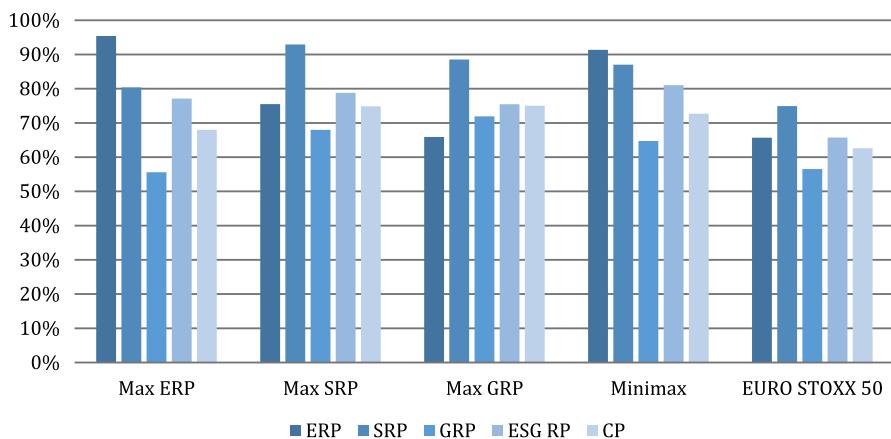


Fig. 4 Extra-financial performance of portfolios built with EURO STOXX 50's components. Note ERP-Environmental Risk Performance, SRP-Social Risk Performance, GRP-Governance Risk Performance, ESG RP-ESG Risk Performance and CP-Controversy Performance

Table 5 Extra-financial performance of portfolios built with EURO STOXX 50's components

No	Extra-financial performance	Max ERP portfolio (%)	Max SRP portfolio (%)	Max GRP portfolio (%)	Minimax portfolio (%)	EURO STOXX 50 (%)
1	ERP	95.41	75.52	65.89	91.37	65.70
2	SRP	80.37	92.94	88.55	87.04	74.94
3	GRP	55.59	67.97	71.93	64.74	56.52
4	ESG RP	77.12	78.81	75.46	81.05	65.72
5	CP	68.00	74.87	75.02	72.70	62.60

ERP environmental risk performance, SRP social risk performance, GRP governance risk performance, ESG RP ESG risk performance and CP controversy performance

5.2 Illustration of the Methodology's Application

In this section, we specify the customizable parameters' values used in the empirical testing of the proposed model. Then, we describe the results obtained by applying the proposed methodology to the EURO STOXX 50.

Table 3 indicates the values that we selected concerning the customizable parameters of the proposed model. To be consistent, identical hard constraints were applied to all the portfolios.

Figure 3 shows a concentration of mid to high-ERP stocks within the EURO STOXX 50, with an average and a median of 64% and 76% respectively. The concentration is even more marked for high-SRP stocks, with an average and a median of 73% and 75% correspondingly. On the contrary, the average of stocks' GRP decreases to 54% and its median to 53%. More generally, Table 4 indicates

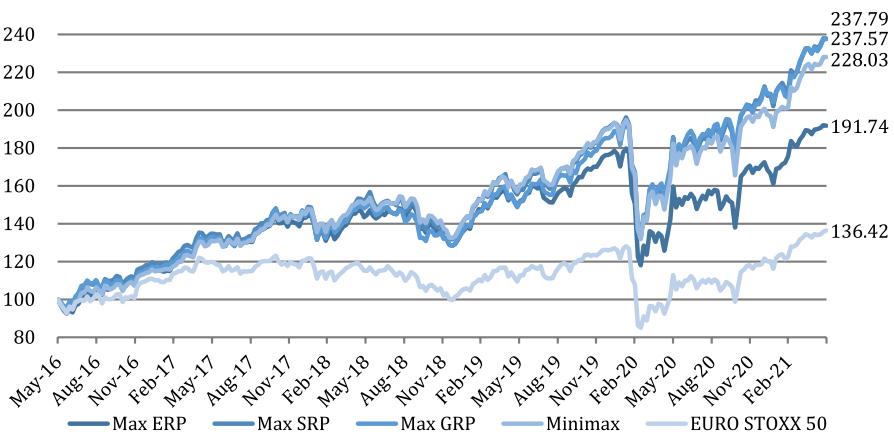


Fig. 5 Cumulative returns of portfolios built with EURO STOXX 50's components. Note ERP-Environmental Risk Performance, SRP-Social Risk Performance and GRP-Governance Risk Performance

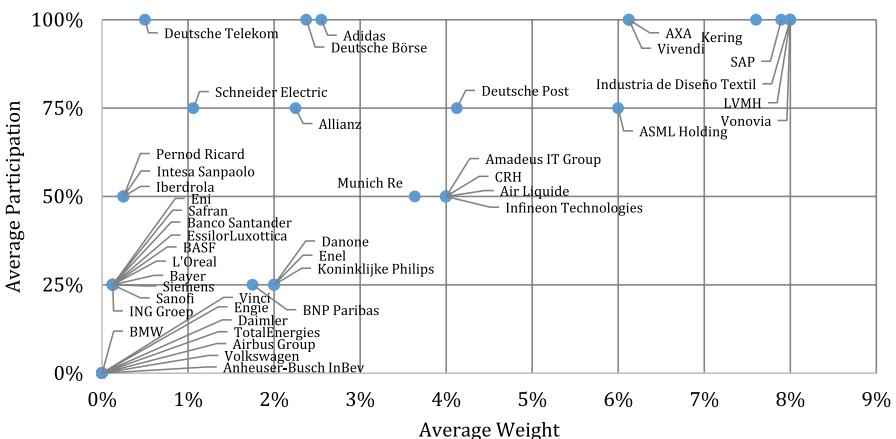


Fig. 6 Average participation and average weight of EURO STOXX 50's components in portfolios

an average of stocks' ESG RP of 61% and a median of 75%. Both average and median of stocks' CP equate to 64%.

Figure 4 and Table 5 compare the ESG RP (including each pillar's risk performance) and the CP of the EURO STOXX 50 with its associated minimax portfolio, as well as the max ERP, max SRP and max GRP portfolios. While respecting hard constraints previously set, the maximum ERP, SRP and GRP achievable using EURO STOXX 50's components are 95.41%, 92.94% and 71.93% correspondingly. In comparison to these three objectives, the minimax portfolio provides an ERP of 91.37% (deviation of 4.04 percent points from the maximum ERP), an SRP of 87.04% (deviation of 5.90 percent points from the maximum SRP) and a GRP of 64.74% (deviation of 7.19 percent points from the maximum

GRP). As each pillar's risk performance is enhanced in the minimax portfolio, its ERP, SRP and GRP all significantly surpass the ones of the EURO STOXX 50. Thus, the ESG RP of the minimax portfolio amounts to 81.05%, strongly outperforming the EURO STOXX 50's ESG RP of 65.72%. Regarding the controversy, it is worth noting that both the maximum SRP and the maximum GRP portfolios provide a strong CP close to 75.00%, compared to 68.00% for the maximum ERP portfolio. The minimax portfolio records a CP of 72.70%, greatly outperforming the EURO STOXX 50 and its CP of 62.60%.

As per Fig. 5, all our portfolios strongly outperform the EURO STOXX 50 in terms of financial performance. Over five years, the max SRP portfolio profits from the highest total return of 137.79%, closely followed by the max GRP portfolio recording a total return of 137.57%. The minimax portfolio lies in third position with a total return of 128.03%. The max ERP portfolio provides the lowest total return of our portfolios, reaching 91.74%, which is still about 2.5 times the 36.42% total return of the EURO STOXX 50.

Figure 6 indicates the average participation and the average weight of each EURO STOXX 50's component within the four built portfolios, i.e., the max ERP portfolio, the max SRP portfolio, the max GRP portfolio and the minimax portfolio. Generally, it is noticeable that the higher the average participation, the higher the average weight. In fact, 7 out of the 10 stocks participating to all the portfolios have an average weight above 6%. Only 4 stocks participate to 3 portfolios, their average weights ranging from 1 to 6%. Out of the 8 stocks participating to 2 portfolios, 3 have a low average weight of 0.25%, the others having an average weight up to 4.00%. Out of the 14 stocks participating to 1 portfolio, 10 have a low average weight around 0.13%. Finally, 13 stocks are never part of our portfolios.

Figure 7 shows that the minimax portfolio solely allocates weights to EURO STOXX 50 components with an ESG RP of at least 70.42%. 11 out of the 16 selected stocks see their weight hitting the 8.00% upper bound. In comparison, the

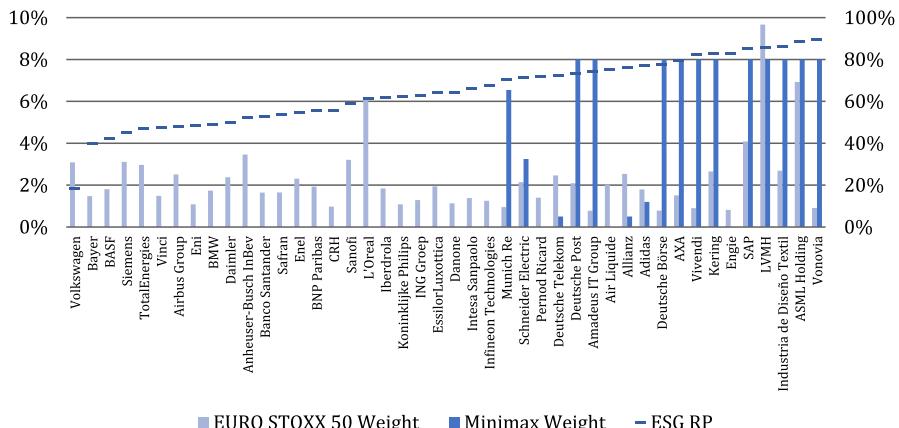


Fig. 7 Weight comparison of EURO STOXX 50's components in index and in minimax portfolio, sorted by ascending order of ESG risk performance. Note ESG RP-ESG Risk Performance

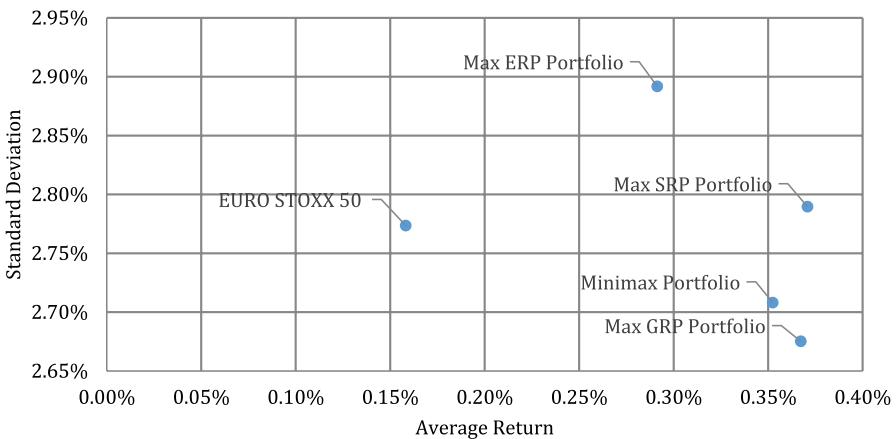


Fig. 8 Risk-return mapping of portfolios built with EURO STOXX 50's components. Note ERP-Environmental Risk Performance, SRP-Social Risk Performance and GRP-Governance Risk Performance

weights of components within the index are much more spread across the entire ESG RP spectrum.

Figure 8 maps the risk-return of our portfolios compared to the EURO STOXX 50. We estimate the risk using the standard deviation of the portfolios' weekly returns over the 5 years considered. As measure of return, we consider the average of the portfolios' weekly returns over the same time horizon. All our portfolios outperform the EURO STOXX 50 in terms of return. However, solely the max GRP portfolio and the minimax portfolio are less risky than the benchmark.

5.3 Aggregate Results

Each minimax portfolio produced by the proposed model materially outperforms its benchmark, according to Fig. 9a. The DJIA's minimax portfolio takes the lead with a 137.06% total return over five years. It is followed by the EURO STOXX 50's minimax portfolio and its 128.03% total return. This minimax portfolio records the largest gap in 5-year total return with its benchmark, compared to all the other minimax portfolios. The two minimax portfolios using CAC 40 and DAX components have a lower total return than the DJIA, but still outperform their own benchmark. In terms of average return, the minimax portfolios and their benchmarks range from 0.16 to 0.36% according to Fig. 9b and Table 6. They are led by the DJIA's and the EURO STOXX 50's minimax portfolios. The DJIA's minimax portfolio is the less risky. The other minimax portfolios are less or as risky as almost all benchmarks, to the exception of the DJIA benchmark. Furthermore, we note that all our portfolios have a Sharpe ratio above their respective benchmark. Based on these results, we conclude that the proposed model provides portfolios materially outperforming their benchmark in the long term with better risk-adjusted returns.

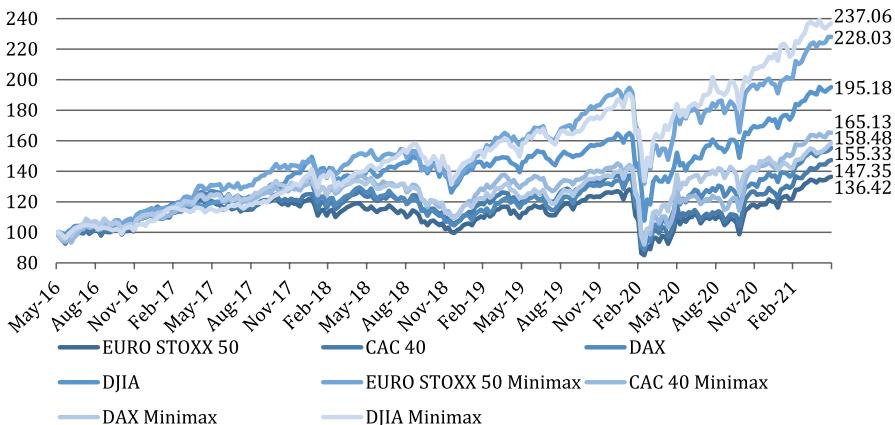
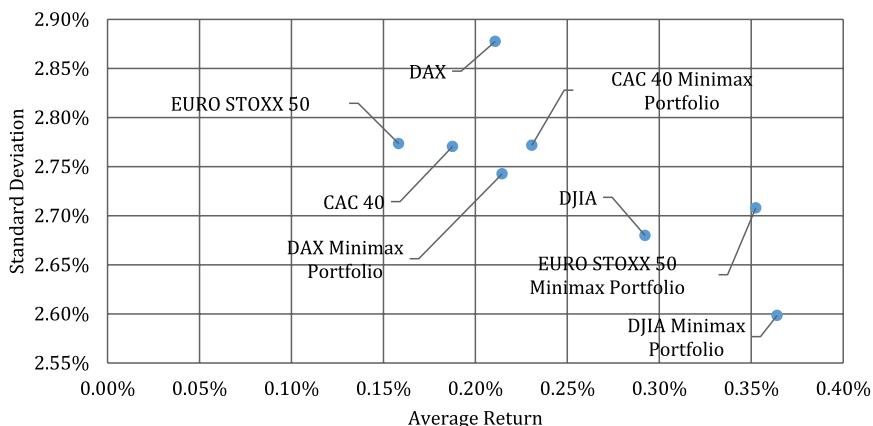
(a) Cumulative returns of minimax portfolios and benchmarks**(b)** Risk-return mapping of minimax portfolios and benchmarks

Fig. 9 **a** Cumulative returns of minimax portfolios and benchmarks. **b** Risk-return mapping of minimax portfolios and benchmarks

Figure 10a particularly illustrates the strong ERP of all the minimax portfolios, led by the DJIA's minimax portfolio. More broadly speaking, the DAX's minimax portfolio provides both the best ESG RP and CP, while the CAC 40's minimax portfolio faces both the lowest ESG RP and CP among the minimax portfolios. Figure 10b indicates the excess of performance of each minimax portfolio over its benchmark for each extra-financial dimension. It is worth noting that almost every minimax portfolio records the

Table 6 Risk-adjusted returns of minimax portfolios and benchmarks

No	Portfolios & benchmarks	Average return (%)	Standard deviation (%)	Sharpe ratio
1	EURO STOXX 50 Minimax	0.35	2.71	0.1302
2	EURO STOXX 50	0.16	2.77	0.0571
3	CAC 40 Minimax	0.23	2.77	0.0833
4	CAC 40	0.19	2.77	0.0677
5	DAX Minimax	0.21	2.74	0.0782
6	DAX	0.21	2.88	0.0733
7	DJIA Minimax	0.36	2.60	0.1401
8	DJIA	0.29	2.68	0.1091

highest excess of performance in at least one dimension. In fact, the EURO STOXX 50's minimax portfolio has the highest excess of ERP. The DJIA's minimax portfolio has the highest excess of SRP and GRP—the DAX's minimax portfolio having an excess of GRP almost as high. The CAC 40's minimax portfolio has the highest excess of CP. On a general level, the DJIA's minimax portfolio also records the highest excess of ESG RP. Based on these results, we conclude that the proposed model provides portfolios materially outperforming their benchmark for each extra-financial dimension. We also conclude that even if an extra-financial dimension is preferred over the others with a higher weight (e.g., the environmental one in our illustration), the excess of performance might be the highest in another extra-financial dimension. It might be explained by the fact that the benchmark already provides a relatively good performance in the preferred extra-financial dimension—due to relatively high weights in companies performing well in this dimension—thus leaving less room for improvement in this very dimension.

6 Conclusions

In this paper, we present a portfolio selection model incorporating investors' ESG preferences. The proposed model consists of a multi-objective minimax-based optimization model focused on ESG risk performance. The environmental, social and governance risk performances are defined as three investment objectives that we attempt to maximize by finding the best trade-off in line with the investors' ESG profile. As investors may have divergent priorities in terms of extra-financial criteria, the degree of importance attributed to each ESG dimension is a customizable parameter in the model. Additionally, the controversy performance of the portfolio is bounded according to investors' preferences. We identify the reliability of ESG risk scores and controversy levels used as inputs to be a key component in the effectiveness of the proposed model. We assess its validity through an empirical testing on the EURO STOXX 50, the CAC 40, the DAX and the DJIA, over a 5-year period, with a focus on portfolio decarbonation. Presenting a better ESG risk performance compared to their benchmarks, the minimax portfolios produced by the

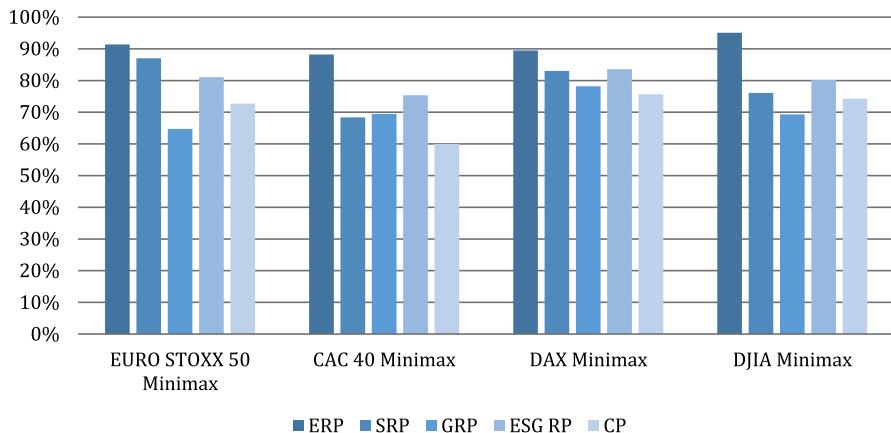
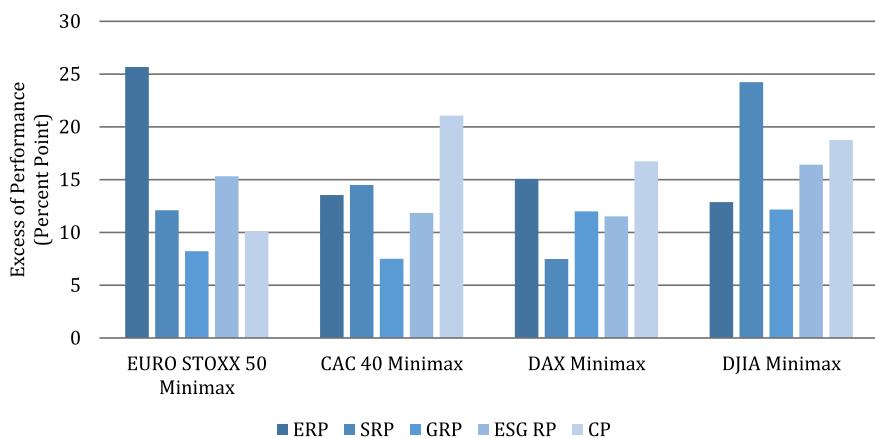
(a) Extra-financial performance of minimax portfolios**(b)** Excess of extra-financial performance provided by minimax portfolios over their benchmark (in percent point)

Fig. 10 **a** Extra-financial performance of minimax portfolios. Note ERP-Environmental Risk Performance, SRP-Social Risk Performance, GRP-Governance Risk Performance, ESG RP-ESG Risk Performance and CP-Controversy Performance. **b** Excess of extra-financial performance provided by minimax portfolios over their benchmark (in percent point). Note ERP-Environmental Risk Performance, SRP-Social Risk Performance, GRP-Governance Risk Performance, ESG RP-ESG Risk Performance and CP-Controversy Performance]

model appear to provide higher returns without implying a higher volatility. With the bigger picture in mind, the proposed model could be extended to other asset classes, beyond equities. Finally, we note that future research could focus on testing the model with Monte Carlo simulation.

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Declarations

Conflict of interest The authors have not disclosed any competing interests.

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