Hedging Climate Risk

by

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Abstract

This paper presents a simple dynamic investment strategy that allows long-term passive investors to hedge climate risk without sacrificing financial returns. We illustrate how tracking error can be almost eliminated even for a low carbon index that has 50% less carbon footprint than its benchmark. By investing in such a decarbonized index, investors are holding in effect a "free option on carbon": as long as the introduction of significant limits on CO_2 emissions is postponed our low carbon index obtains the same return as the benchmark index, but when CO_2 emissions are integrated by the market, it starts outperforming the benchmark.

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Summary

Whether or not one agrees with the scientific consensus on climate change, uncertainty around climate legislation should be understood to be an increasingly important risk factor, with the potential to greatly affect corporate profits and investors' financial returns. We analyze a simple dynamic investment strategy that allows long-term passive investors to hedge climate risk on their core equity portfolios without sacrificing financial returns. Our hedging strategy goes beyond a simple divestment of high carbon footprint or stranded assets stocks. This is just the first step. The second step is to optimize the composition of the low carbon portfolio so as to keep a similar aggregate risk exposure by minimizing the tracking error with the reference benchmark index. We illustrate how tracking error can be almost eliminated even for a low carbon index that has 50% less carbon footprint. The low carbon portfolios in existence that have been constructed in this way have so far matched or outperformed their benchmark. By investing in such a decarbonized index investors are holding, in effect, a "free option on carbon": as long as the introduction of significant limits on CO_2 emissions is postponed they are essentially able to obtain the same returns as on a benchmark index, but the day when CO_2 emissions are integrated by the market, the low carbon index will outperform the benchmark.

1. Introduction

Whether or not one agrees with the scientific consensus on climate change, climate risk and climate change mitigation policy risk are worth hedging. The evidence on rising global average temperatures has been the subject of recent debates, especially in light of the apparent slowdown in global warming over the period of 1998 to 2014.[1] Naturally, the perceived slowdown has confirmed the beliefs of climate change doubters and fuelled a debate on climate science widely covered by the media. This ongoing debate is stimulated by three important considerations.

The first most obvious consideration is that not all countries and industries are equally affected by climate change. As in other policy areas, the existence of winners and losers from the introduction of a new regulation naturally gives rise to policy debates between the losers, who exaggerate the costs, and the winners, who emphasize the urgency of the new policy. The second consideration is that climate mitigation has typically not been a "front burner" general political issue and politicians often tend to prefer to "kick the can down the road" rather than introduce policies that are costly in the short run and risk alienating their constituencies, all the more so if there is a perception that the climate-change debate it is not yet fully settled and that climate change mitigation may not be in need of urgent attention. The third consideration is that, although the scientific evidence on the link between CO_2 emissions and the greenhouse effect is overwhelming, there is considerable uncertainty regarding the rate of increase in average temperatures over the next 20 or 30 years and the effects on climate change. There is also considerable uncertainty regarding the "tipping point" beyond which catastrophic climate

[1] The latest study in *Science* by a team of the National Oceanic and Atmospheric Administration (NOAA) led by Thomas R. Karl (2015), however, finds that this perceived slowdown was all due to measurement errors in ocean temperatures.

dynamics are set in motion.[2] As with financial crises, the observation of growing imbalances can alert analysts to the inevitability of a crash but still leaves them in the dark as to when the crisis is likely to occur.

This uncertainty should be understood to be an increasingly important risk factor for investors, particularly long-term investors. The climate science consensus tells us at a minimum that the *risks* of a climate disaster are substantial and rising with continued massive CO_2 emissions. Moreover, as further evidence of climate events linked to human emissions of CO_2 accumulates and global temperatures keep rising, there is also an increased likelihood of policy intervention to limit these emissions.[3] In case of delayed action and significantly higher temperatures, radical climate policies resulting in a steep rise in the price of carbon become more likely. Of course, other plausible scenarios can be envisioned such as no global agreement on introducing comprehensive policies to significantly limit global GHG emissions being reached in the next Climate Conference in Paris in 2015 (COP21), or in the foreseeable future. From an investor's perspective this means that there is a *risk* with respect to both climate change and climate mitigation policies. Thus, investors should—and some are beginning to—factor in climate risk in their investment policies. However, it is fair to say that there is still little awareness among

[2] See Litterman (2012) for an analysis of the consequences of this deep uncertainty for the economics of carbon pricing.

[3] The United Nations Framework Convention on Climate Change (UNFCCC) coordinates global policy efforts towards the stabilization of GHG concentrations in the atmosphere, with a widely assented policy target for the coming decades of limiting GHG emissions in order to keep average temperatures from rising above 2°C by 2050. However, no concrete policies limiting GHG emissions have yet been agreed that make this target a realistic prospect. Although the process led by UNFCCC has stalled following the adoption of the Kyoto protocol, a number of countries have taken unilateral steps to limit GHG emissions in their respective jurisdictions. The next Conference of Parties on Climate Change (UNFCC Conference) that will be held in Paris in December 2015 is seen by many observers as a crucial milestone—if not the last opportunity—to limit global warming to 2°C. See Appendix A for further details.

(institutional) investors about this *risk factor*.[4] Few investors are aware of the carbon footprint and climate impact of the companies in their portfolios, and among those holding oil and gas company stocks, equally few are aware of the risks they face with respect to these companies *stranded assets*.[5]

In this paper, we revisit and analyze a simple dynamic investment strategy that allows long-term passive investors—a huge institutional investor clientele comprising pension funds, insurance and re-insurance companies, central banks and sovereign wealth funds—to significantly hedge climate risk while essentially sacrificing no financial returns. One of the main challenges for long-term investors is to narrow down the timing of climate mitigation policies. To again make a helpful analogy with financial crises, it is extremely risky for a fund manager to exit (or short) an asset class that is perceived to be overvalued and subject to a speculative bubble, because the fund could be forced to close as a result of massive redemptions before the bubble has burst. Similarly, an asset manager looking to hedge climate risk by divesting from stocks with high carbon footprints bears the risk of underperforming his benchmark for as long as climate mitigation policies are postponed and market expectations about their introduction are low. Such a fund manager may well be wiped out long before serious limits on CO_2 emissions are introduced.

[4] A handful of organizations contribute to raising awareness on carbon risk among institutional investors. Among these we should mention the Portfolio Decarbonization Coalition launched with the support of the United Nations in September 2014. This organization gathers pioneers in the decarbonization of portfolios that share knowledge and best practices, with a $100bn target in institutional investment decarbonization reached by the time of the COP21. As of August 2015, its 16 members already claim $62bn of decarbonized investments. For more information, see: http://unepfi.org/pdc/

[5] See Appendix B for further information on stranded assets.

A number of "green" financial indexes have already been in existence for some years. These indices fall into two broad groups: (i) pure-play indices which focus on renewable energy, clean-technology and/or environmental services and (ii) "decarbonized" indices (or "green beta indices"), whose basic construction principle is to take a standard benchmark such as the S&P 500 or NASDAQ 100 and to remove or underweight the companies with relatively high carbon footprints[6] from the list of constituents. The first family of green indices offers no protection against the timing risk of climate-change mitigation policies. But the second family of decarbonized indices does: An investor holding such a decarbonized index is hedged against the timing risk from climate mitigation policies, that are expected to hit disproportionately high carbon-footprint companies, as the decarbonized indices are structured to maintain a low tracking error with respect to the benchmark indexes.

The success of pure-play indices has so far been limited. One important reason highlighted in Table 1 is that since the onset of the financial crisis in '07-'08, these index funds have significantly underperformed market benchmarks.

[Insert Table 1]

[6] The carbon footprint of a company refers to its annualized GHG emissions relative to a financial metric (e.g. revenue or sales) or a relevant activity metric (e.g. units produced). See Section 3 and Appendix C for further details.

Besides the fact that clean tech had been over-hyped[7], one of the reasons why these indexes have underperformed is that some of the climate mitigation policies in place before the financial crisis have been scaled back (e.g. in Spain). In addition, financial markets may have rationally anticipated that one of the consequences of the financial crisis is the likely postponement of the introduction of limits on CO_2 emissions. These changed expectations benefited the carbon intensive utilities and energy companies relatively more and may explain the relative under-performance of the green pure-play indexes. More importantly, the reach of the pure-play green funds is very limited as it concentrates investments in a couple of subsectors and cannot in any case serve as a basis to build a core equity portfolio for institutional investors.

The basic point underlying a climate-risk hedging strategy using decarbonized indices is to go beyond a simple divestment policy or investments in only pure-play indices, and instead to keep a similar aggregate risk exposure as standard market benchmarks. Indeed, divestment of high carbon-footprint stocks is just the first step. The second key step is to optimize the composition and weighting of the decarbonized index so as to minimize the *tracking error* (TE) with the reference benchmark index. It turns out that TE can be virtually eliminated, while at the same time the overall carbon footprint of the decarbonized index is substantially lower than the reference index (close to 50% in terms of both carbon intensities and absolute carbon emissions). The track record of existing decarbonized indices so far has been to essentially match or even outperform the benchmark index.[8] In other words, investors holding a decarbonized index have been able to significantly reduce their carbon footprint exposure without sacrificing any financial returns. These investors are, in effect, holding a "free option on carbon": as long as the

[7] Gartner. "Interpreting Technology Hype." See: http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp
[8] See Sections 3 and 4 for performance results of the "decarbonized" S&P500 and MSCI Europe indices.

introduction of significant limits on CO_2 emissions is postponed they are essentially able to obtain the same returns as on a benchmark index, but the day when CO_2 emissions are priced in a meaningful and consistent manner and limits on CO_2 emissions are introduced the decarbonized index should outperform the benchmark. [9] A climate risk hedging policy around decarbonized indices is essentially an unlevered minimum risk arbitrage policy, taking advantage of a currently mispriced risk factor (carbon risk) in financial markets. Granted, larger arbitrage gains are obtainable by taking larger risks, and, if anything, this strategy errs on the side of caution. However, this strategy is particularly well-suited for a long-term passive investor clientele that seeks to maximize long-term returns while limiting active stock trading over time.

Our paper is organized as follows. We begin by describing in greater detail the basic concept of a *decarbonized index without relative market risk* and the advantages and potential concerns with this investment strategy. We continue by describing the decarbonized portfolio used by AP4 for its U.S., EM, and Europe equity portfolios and how they have performed so far. Finally, we address the public policy implications of these climate risk hedging strategies and offer concluding remarks on the general index decarbonization approach.

[9] The mechanics affecting the relationship between carbon legislation, technological changes, and financial returns are obviously complex and not straightforward. However, the purpose of decarbonized indices is to circumvent these difficulties by focusing on an area with somewhat less uncertainty, the companies most exposed to carbon risk. See Section 2 for further details.

2. A Green Index without Relative Market Risk: the Basic Concept

Investor perceptions of lower financial returns from green index funds could explain why green indexes have to date remained a niche market. But, another reason may be the design of most existing green indices, which lend themselves more to a bet on clean energy than a hedge against carbon risk. In contrast, the design we support is the one that allows passive long-term investors to hedge carbon risk. Thus, the goal is not just to minimize exposure to carbon risk by completely divesting from any companies that have a carbon footprint exceeding a given threshold, but also to minimize the tracking error of the decarbonized index with the benchmark index. The reasons why we support this design are that it implements a true dynamic hedging strategy for passive investors, and that it can easily be scaled to achieve significant impact, not only on portfolios' footprints but eventually also on the real economy. [10]

The basic idea behind index decarbonization is, thus, to construct a portfolio with fewer composite stocks than the benchmark, but with similar aggregate risk exposure to all priced risk factors than the benchmark index. It is possible to do this because, as Koch and Bassen (2013) have shown, carbon risk is asymmetrically concentrated in a few firms.[11] Ideally, the only major difference in aggregate risk exposure between the two indices would then be with respect to the carbon risk factor, which would be significantly lower for the decarbonized index. As long as carbon risk stays unpriced by the market, the two indices will generate similar returns (offer the same compensation for risk demanded by the representative investor), thus achieving no or

[10] See http://unepfi.org/pdc/wp-content/ to explore the links between portfolios decarbonization and the incentives it can provide to actors in the real economy to re-channel their own investments and lower their carbon footprint.

[11] Koch and Bassen (2013) estimate an "equity value at risk from carbon" for European Electric Utilities, which is driven by their fossil-fuel mix, and show that a filter on companies with a high carbon-specific risk reduces the exposure to global carbon-risk without otherwise affecting the risk-return performance of an equity portfolio.

minimal TE. But, once carbon risk is priced by the market, or is expected to be priced, the decarbonized index should start outperforming the benchmark.

The central underlying premise of this strategy is that financial markets currently underprice carbon risk. Moreover, our fundamental belief is that eventually, if not in the near future, financial markets will begin to price carbon risk. If our premise is taken for granted, it leads inevitably to the conclusion that a decarbonized index is bound to provide superior financial returns to the benchmark index. We believe that the evidence in support of our main underlying premise is overwhelming. Virtually all financial analysts currently overlook carbon risk. Only last year did a discussion about stranded assets make it into a report of a leading oil company for the first time. And the report mostly denied any concern that a fraction of proven reserves might ever become stranded assets. Only a few specialized financial analysts[12] have so far factored in stranded assets into their valuation models of oil company stocks. Nor, apart from a few exceptions,[13] do financial analysts ever evoke carbon pricing risk in their reports to investors. In sum, current analysts' forecasts assume by default that there is no carbon risk. Under these circumstances one would have to stretch one's imagination to explain that somehow financial markets currently price carbon risk correctly. It is even more implausible that in some way financial markets currently price carbon risk excessively. It is only in this latter scenario that investors in a decarbonized index would face lower financial returns than in the benchmark index.

[12] Mostly ESG analysts, who until recently were largely segregated from mainstream equity analyst teams with an audience predominantly consisting of ethical investors.

[13] HSBC (2008) is a notable exception of early integrated analysis of the materiality of carbon risk in the Oil and Gas as well as Coal industries. Since then, Carbon Tracker Initiative has been instrumental in raising awareness on stranded asset issues and energy-focused analysts are more and more integrating carbon related risk in a consistent manner (see for instance HSBC 2012 or Kepler-Chevreux 2014).

Some might object that our fundamental belief that financial markets will price carbon risk in the future is not very plausible. After all, the evidence from climate talks failures following Kyoto suggests if anything that carbon pricing in the near future is extremely unlikely. That may be so, but if that were the case our investor in the decarbonized index would simply match the returns of the benchmark index, a worst-case scenario. Any concrete progress in international negotiations from the current status-quo will change financial market expectations on carbon risk and is likely to result in higher financial returns on the Low-TE index relative to the benchmark index.

The decarbonized index optimization problem. Accepting our basic premise and fundamental belief, the next question is how one goes about constructing the green index. There are several possible formulations of the problem in practice. One formulation is to begin by eliminating high carbon footprint composite stocks with the objective of meeting a target carbon footprint reduction for the green index, and then to reweight the stocks that remain in the green index so as to minimize tracking error with the benchmark index. The dual of this formulation is to begin by imposing a constraint on maximum allowable tracking error with the benchmark index, and subject to this constraint, to exclude and reweight composite stocks in the benchmark index so as to maximize the carbon footprint reduction of the green index. Although there is no compelling reason to choose one of these formulations over the other, we have favored the formulation that seeks to minimize tracking error subject to meeting a carbon footprint reduction target.

Another relevant variation in the design of the constrained optimization problem is whether to impose at the outset the complete exclusion of composite stocks of the worst performers in terms of carbon footprint, or whether to allow the construction of the green index to simply underweight high carbon footprint stocks without completely excluding them. The latter formulation is of course more flexible, but it has some other drawbacks, which we shall discuss below.

Although there are many more possible formulations of the constrained optimization problem for the construction of a decarbonized index that trades off exposure to carbon, tracking error and expected returns, we confine our analysis to essentially two alternative formulations. We describe each of these formulations more formally below, under the simplifying assumption that there is only one sector represented in the benchmark index.

The two portfolio optimization problems can then be represented as follows. Suppose that there are N constituent stocks in the benchmark index, and that the weight of each stock in the index is given by $w_i^b = (\frac{Mkt\ Cap\ (i)}{Total\ Mkt\ Cap})$. Suppose next that each constituent company is ranked in decreasing order of carbon intensity, q_l^i, with company l = 1 having the highest carbon intensity and company l = N the lowest (each company is thus identified by two numbers (i,l) with the first number referring to the company's identity and the second its ranking in carbon intensity).

In the first problem, the green portfolio can then be constructed by choosing new weights w_i^g for the constituent stocks to solve the following minimization problem:

$$Min\, TE = sd(R^g - R^b)$$

subject to:

$$w_j^g = 0\, for\ all\ j = 1, \dots k.$$

$$0 \leq w_i^g\, for\ all\ i = k+1, \cdots, N\ .$$

That is, the decarbonized index in this first problem is constructed by first excluding the *k* worst performers in terms of carbon intensity and reweighting the remaining stocks in the green portfolio so as to minimize TE.[14] This "decarbonization" method follows transparent rules of exclusion, whatever the threshold *k*.

In the second problem formulation the first set of constraints, $w_j^g = 0\, for\ all\ j = 1, \dots k$, is replaced by a constraint that the green portfolio's carbon intensity should be smaller than a given threshold: $\Sigma_{l=1\dots N} q_l w_l^g \leq Q$. In other words, the second problem is a design, which potentially does not exclude any constituent stocks from the benchmark index, and only seeks to reduce the carbon intensity of the index by reweighting the stocks in the green portfolio. While the second problem (*pure optimization*) formulation dominates the first (*transparent rules*) for the same target aggregate carbon intensity Q, as it has fewer constraints, it has a significant drawback in terms of opacity of the methodology and lack of a clear signal on which constituent stocks are excluded on the basis of their relatively high carbon intensity.

[14] A multi-sector generalization of this optimization problem can also break down the first set of constraints into companies that are excluded on the basis of their poor ranking in carbon intensity across all sectors, and for the remaining constituent firms, companies that are excluded within each sector based on either their relatively poor carbon intensity score or their relatively high stranded assets relative to other companies in their sector.

Optimization procedure. For both problem formulations the ex ante TE, which is given by the estimated standard deviation of returns of the decarbonized portfolio from the benchmark, is estimated using a multifactor model of aggregate risk (see Appendix D for more detailed information). This multifactor model significantly reduces computations, and the decomposition of individual stock returns into a weighted sum of common factor returns and specific returns provides a good approximation of expected returns of individual stocks. More formally, under the multifactor model the TE minimization problem has the following structure:

$$Min\left\{\sqrt{(W^p - W^b)'\left(\beta\Omega_f\beta' + \Delta^{AR}\right)(W^P - W^b)}\right\}$$

Subject to:

$$w_j^g = 0 \; for \; all \; j = 1, \dots k.$$

$$0 \leq w_i^g for \; all \; i = k+1, \cdots, N \, .$$

Where $(W^p - W^b)$ is the vector of the difference in portfolio weights of respectively the decarbonized portfolio and the benchmark, Ω_f is the variance-covariance matrix of factors, β is the matrix of factor exposures, and Δ^{AR} is the diagonal matrix of specific risk variances.

Risk mitigation benefits of low tracking error. To explore more systematically the potential benefits of achieving a bounded tracking error, we have run a number of simulations with the pure optimization methodology and determined a TE-carbon efficiency frontier for a decarbonized index constructed from the MSCI Europe. As we illustrate in Figure 1 below, achieving a nearly 100% reduction in the MSCI Europe carbon footprint would come at the price of a huge tracking error of more than 3.5%.[15]

[15] When not specified, tracking error is calculated ex ante.

[Insert Figure 1]

Such a large TE would expose investors in the decarbonized index to significant financial risk relative to the benchmark even in a good scenario where, as a result of climate mitigation policies, the decarbonized index is expected to outperform the benchmark. An illustration of the risk investors might be exposed to with a large TE, and how this risk can be mitigated by lowering TE, is given in Figure 2 below. We first posit a scenario where the expected yearly return from the green index is 2.5% higher than the benchmark[16] and show that, according to a two standard deviation confidence interval, such a 3.5% TE could expose investors to losses relative to the benchmark in the negative scenario.

As Figure 2 also illustrates, if we lower the TE of the decarbonized index from 3.5% to 1.2%, then even in the worst case scenario the decarbonized index would generate returns at least as high as the benchmark.

[Insert Figure 2]

Illustrative Example. The following simple example illustrates in greater detail how a Low carbon Low TE index might be constructed and how its financial returns—relative to the benchmark—would vary with (expectations of) the introduction of carbon taxes. We consider a portfolio of four stocks (A, B, C, D) each priced at 100. The first two stocks (A, B) are, say, oil

[16] This level of outperformance over such a time frame is hypothetical and only for illustrative purposes. Although we are hopeful that a scenario of radical climate risk mitigation policy measures in the near future is possible (see Mercer, 2011) global climate policy implementation and its potential impact on equity valuation remains understandably a very speculative exercise.

company stocks; stock C is outside the oil industry but its price is perfectly correlated with oil companies' stock price, and stock D is a company whose stock price is uncorrelated with the oil industry. The respective returns on each of these stocks before carbon taxation are respectively: 20%, 20%, 20%, and 30%. We take stocks A and B to have relatively high carbon footprint, which would expose them to relatively high implied carbon taxation, respectively 40% and 10% of their earnings. We assume, on the other hand, that stocks C and D have no carbon tax exposure. We then construct the Low carbon Low TE index as follows: i) we filter out entirely stocks A and B; ii) we treble the weighting on stock C to maintain the same overall exposure to the oil sector as the benchmark portfolio; iii) we leave the weighting on stock D unchanged. Should carbon taxes be expected to be introduced then the stock price of company A and B respectively will drop to 72 and increase to 108 while the stock price of companies C and D respectively will increase to 120 and 130. What are the implications for returns on the Low carbon Low TE index relative to the benchmark? Under this scenario the Low TE index would outperform the benchmark by 14%.

Tracking error management and carbon risk repricing. An index manager seeks to limit ex ante TE. However, some enhanced indexes such as the decarbonized indexes also seek to increase returns relative to the benchmark. Although the two goals may seem in conflict, one should note that the optimization program focuses on ex ante TE and excess returns are necessarily measured ex post. Therefore, if the risk model used to limit the ex ante TE does not take into account carbon risk (or any factor responsible for a divergence of returns), a small ex ante can be compatible with active returns ex post. Two polar carbon repricing scenarios can be considered, either a smooth repricing with moderate regulatory and technological changes progressively

impairing the profitability of carbon intensive companies, or a sharp repricing, caused by non-anticipated disruptive technologies or regulations. In the first scenario, an investor could experience active positive returns with an ex post TE in line with an ex ante TE. In the second scenario, investors in a decarbonized index could experience a peak in ex post TE, with active positive returns.

3. Beyond Optimization: Methodological Considerations and Caveats

Benefits of a clear signaling through transparent rules. As all issuers well understand, inclusion or exclusion in an index matters and is a newsworthy event. We believe that inclusion in a decarbonized index ought to have a similar value. Clearly communicating which constituent stocks are in the decarbonized index not only rewards the companies included in the index for their efforts in reducing their carbon footprint but also helps discipline the companies that are excluded.This pressure in turn might induce these companies to take actions to reduce their carbon footprint and to reward their CEOs for any carbon footprint reductions.[17] As companies' exclusion from the index will be reevaluated on a yearly basis, it will also induce healthy competition to perform on carbon footprint, with the goal of rejoining the index.[18] Finally, a clear communication on exclusion criteria based on carbon footprint will inspire a debate on whether GHG emissions are properly measured and lead to improvements in the methodology for determining a company's carbon footprint.

[18] An interesting example of such mechanism is the JPX-Nikkei 400, a new index based both on standard quantitative criteria, such as return on equity, operating profit, and market value, and more innovative qualitative criteria, such as governance requirements of least two independent outside directors, etc. Launched with the support of Japanese giant pension fund Government Pension Investment Fund (GPIF) to incite better corporate performance, it was quickly renamed the "shame index" and is now carefully scrutinized by analysts and companies are taking the inclusion in the index more and more seriously.

Other Tradeoffs. A number of other tradeoffs are involved in the design of a decarbonized index. A first obvious balancing question concerns the sector composition of the benchmark index. To what extent should the decarbonized index seek to preserve the sector balance of the benchmark? And, while seeking to preserve sector composition, should the filtering out of high carbon footprint stocks be performed sector-by-sector or overall across the entire benchmark index portfolio? It is often thought that a sector blind filtering out of companies by the size of their carbon footprint would result in an unbalanced decarbonized index that essentially excludes most of the fossil energy sector, electric utilities, mining and materials companies and not much else. Obviously, such an unbalanced decarbonized index would have a very high tracking error and would not be very desirable. Interestingly, however, a study of the world's 100 largest companies has shown that more than 90% of the world's GHG emissions are attributable to other sectors than Oil & Gas (see Climate Counts, 2013). Hence, a sector-by-sector filtering approach can result in a significantly reduced carbon footprint, while still maintaining a roughly similar sector composition as the benchmark. In the next section, we will show more concretely how much reduction in carbon footprint can be achieved by respectively decarbonizing the S&P 500 and the MSCI Europe indices.

One simple way of addressing this issue, of course, is to look at what the TE of the decarbonized portfolio is for the different optimization problems and pick the procedure which yields the decarbonized index with the lowest TE. But there may be other relevant considerations besides TE minimization. For example, one advantage of transparent rules with a sector-by-sector filtering approach (subject to the constraint of maintaining roughly the same sector balance as the

benchmark index) is that it will be more straightforward for the companies whose stocks have been filtered out to determine where they stand in the relevant industry ranking by carbon footprint and what it would take in terms of carbon footprint reduction for their stock to be included in the decarbonized index. In other words, a sector-by-sector filtering approach would foster greater competition within each sector for each company to lower its carbon footprint. Another related benefit of a sector-by-sector filtering approach is that the exclusion of the worst performers in the sector in terms of carbon footprint is likely to generate higher financial returns not only due to the reduced exposure to mispriced carbon risk but also to reduced exposure to firms that fare rather poorly on other material sustainability factors[19] (given that carbon footprint reduction is a good proxy for investments in other material sustainability variables).

Normalization of carbon footprint. As the largest companies in the index are also likely to be the companies with the highest GHG emission levels, a filtering rule that excludes the stocks of companies with the largest absolute emission levels will tend to be biased against the largest companies, which could result in a high tracking error for the decarbonized index. Accordingly, some normalization of companies' carbon footprints would be appropriate. Another reason to normalize the absolute carbon footprint measure is that a filter based on a normalized measure would be better at selecting the least wasteful companies in terms of GHG emissions. In other words, a normalized carbon footprint measure would better select companies based on their energy efficiency. A simple, comprehensive but somewhat rudimentary normalization would be to divide each company's carbon footprint by sales. Normalizations adapted by sector are preferable and could for example take the form of dividing CO_2 emissions by: i) tons of output in

[19] See Khan, Serafeim and Yoon (2015) on the relationship between sustainability investments and shareholder value creation.

the oil and gas sector; ii) sales*kilometer distance in the transport sector; iii) total GWh electricity production in the electric utility sector; iv) square footage of floor space in the housing sector; and v) total sales in the retail sector.

Change in companies' carbon footprints. Ideally the green filter should take into account expected future reductions in carbon footprint resulting from current investments in energy efficiency and reduced reliance on fossil fuels. Similarly, the green filter should penalize more oil and gas companies that invest heavily in exploration with the goal of increasing their proven reserves, which increases the stranded asset risk for these companies. This would provide immediate incentives to companies with exceptionally high carbon footprints to engage in investments to reduce it and it would boost financial returns of the decarbonized index relative to the benchmark.

Caveats. Any time an investment strategy that is expected to outperform a market benchmark is pitched a natural reaction is to ask: where is the catch? As we explained above, the outperformance of the decarbonized index is premised on the fact that carbon risk is currently not priced by financial markets. An obvious potential flaw in our proposed climate risk hedging strategy is thus that financial markets currently overprice carbon risk. As this overpricing is corrected the decarbonized index would underperform the benchmark index. We strongly believe this argument to be implausible as the current level of awareness of carbon risk remains very low outside a few circles of asset owners, a handful of brokers and asset managers. Another highly implausible scenario is that somehow today's high carbon footprint sectors and companies will be tomorrow's low carbon footprint sectors and companies. One story to back such a scenario

could be that the high GHG emitters today have the most to gain from carbon sequestration and will therefore be the first to invest in this technology. If that were the case, the decarbonized index would underperform the benchmark precisely when carbon taxes are introduced. This story is not in itself a crushing objection, since the green filter can easily take into account investments in carbon sequestration as a criterion for inclusion in the index. In the end, this story simply suggests a reason for the carbon filter to take into account measures of predicted future carbon footprint of companies.

A more valid concern is whether companies' carbon footprints are currently correctly measured and if the filtering based on carbon intensity fits for its purpose. Is there a built-in bias in the way carbon footprint is measured, or is the measure so noisy that investors could be exposed to a lot of carbon measurement risks? A number of organizations, such as *Trucost*, *CDP* (formerly *Carbon Disclosure Project*), *South Pole Group*, or *MSCI ESG Research* currently provide carbon footprint measures of the largest publicly traded companies, which sometimes can differ from one organization to another.[20] It has also been observed, for example, that GHG emissions associated with hydraulic fracturing for shale gas are currently significantly underestimated, as the high methane emissions involved in the hydraulic fracturing process *per se* are not counted. Thus, what would appear as a welcome reduction in carbon footprint following the shift away from coal to shale gas according to some current carbon footprint measurements could just be an illusion. Consequently a green filter that relies on this biased carbon footprint measure risks exposing investors to more rather than less carbon risk. As we describe in greater detail in the

[20]See http://www.iigcc.org/events/event/50-shades-of-green-carbon-foot-print-workshop for an attempts at comparing different providers' results within a given universe. The differences that emerged came from different estimation models. That being said, professionals agree that the measures are globally converging towards a much improved harmonization.

Appendix, GHG emissions are divided into three scopes: *Scope 1*, which measures direct GHG emissions; *Scope 2*, which concerns indirect emissions resulting from the company's purchases of energy; and *Scope 3*, which picks up third party emissions (suppliers or consumers) tied to the company's sales. Although Scope 3 emissions may represent the largest fraction of GHG emissions for some companies (e.g. consumer electronics companies or car manufacturers[21]) there is currently no systematic and standardized reporting on these emissions. This is clearly a major limitation, which reduces the effectiveness of all existing decarbonization methodologies. For example, excluding the most polluting companies in the automobiles & components industry based on current emission measures would mostly lead to the exclusion of auto components companies. Automobile manufacturers would largely be preserved, as most of the carbon emissions for a carmaker are Scope 3 emissions. However, as the reliance on decarbonized indices grows in scale it is to be expected that more resources will be devoted to improving the quality of Scope 3 and other categories of GHG emissions. The inclusion of Scope 3 emissions would also better account for green product innovations by materials companies that bolster the transition towards a low carbon economy. For instance, aluminum producers may be excluded under the current GHG measures due to their high carbon intensity even though aluminum will fare better than other materials in the transition to renewable energy.

In addition, there are three evident responses to these existing measurement limitations. First, drawing an analogy with credit markets, a biased or noisy measure of credit risk by credit rating agencies has never been a decisive reason for abolishing credit ratings altogether. Credit ratings have provided an essential reinforcement of credit markets for decades despite important

[21] According to Trucost (2013), for 60% of companies in the MSCI World Index, at least 75% of emissions are from supply chains.

imprecisions in their measurements of credit risk that have been pointed out by researchers of credit markets over time. Second, as with credit ratings, methodologies for measuring carbon footprint will improve over time, especially when the stakes involved in measuring carbon footprint correctly increase as a result of the role of these measures in any green filtering process. Third, the design of the decarbonized index itself offers a protection against carbon footprint measurement risk, for if there is virtually no tracking error with the benchmark then investors in the decarbonized index are to some extent hedged against this risk.

Finally, a somewhat more technical worry is that the stocks that are excluded from the decarbonized index could also be the most volatile stocks in the benchmark index, as these stocks are the most sensitive to speculation about climate change and climate policy. If that is the case, then tracking error cannot be entirely eliminated, but that should not be a reason for not investing in the decarbonized index. On the contrary, the decarbonized index will then also have a higher Sharpe ratio relative to the benchmark commensurate with a higher TE.[22]

To summarize, the strategy for hedging climate risk we advocate is especially suitable for passive long-term investors. Rather than a risky bet on clean energy (at least in the short run) we have described a decarbonized index with a minimal tracking error, which offers passive investors a significantly reduced exposure to carbon risk, while at the same time allowing them, so to speak, to buy time and limit their exposure to the risk with respect to the timing of the implementation of climate policy and a carbon tax. Thus, a key difference in this approach

[22] Moreover, most modern optimization techniques utilize factor exposures and correlations, reducing risk from known systematic factors such as volatility, small cap or beta, therefore reducing this risk by increasing weights of high volatility/low carbon stocks to replace the high carbon stocks.

relative to other existing green indices is to move the focus away from the inevitable transition to renewable energy, to concentrate more on the timing risk with respect to climate policy. As we will illustrate in the next section, it is possible to significantly reduce carbon exposure while at the same time providing maximum insurance against the timing of climate policy by minimizing tracking error with respect to the benchmark index. We believe that this strategy is essentially a win-win strategy for all passive asset owners and managers. Moreover, should this strategy be adopted by a large fraction of the passive index investing clientele, a market representing close to $10tn in assets according to a recent study by BCG (BCG 2014), then pressure on companies to improve their performance on GHG emissions will be felt and debates on carbon emissions are sure to rise in prominence in the financial press.[23]

4. Decarbonized Indices in Practice: How Small are their Carbon Footprints?

There are by now several examples of decarbonized indices. AP4, the Fourth Swedish National Pension Fund, is to our knowledge the first institutional investor to adopt a systematic approach using some of these decarbonized indices to hedge the carbon exposure of its global equity portfolio on a significant scale. In 2012, AP4 decided to hedge its carbon exposure on its U.S. equity holdings in the S&P 500 index by switching to a decarbonized portfolio with low tracking error relative to the S&P 500 (through the replication of the S&P U.S. Carbon Efficient Index). This index excludes the 20% worst performers in terms of carbon intensity (CO_2 / Sales) as measured by *Trucost,* one of the leading companies specializing in the measurement of environmental impacts of publicly traded companies. A first design constraint on the

[23] Beyond the $10 trillion in index funds, the asset owners that are members of CDP represent an asset base as high as $95 trillion (see CDP.net).

decarbonized index is to ensure that stocks removed from the S&P 500 do not exceed a reduction in GICS sector weight of the S&P 500 by more than 50%. A second feature of the S&P U.S. Carbon Efficient Index is to readjust the weighting of the remaining constituent stocks to minimize the tracking error with the S&P 500. Remarkably, this decarbonized index reduces the overall carbon footprint of the S&P 500 by roughly 50%[24] for a TE of no more than 0.5%. This first model of a decarbonized index thus strikingly illustrates that significant reductions in carbon exposure are possible without sacrificing much in financial performance or TE. In fact, AP4's S&P U.S. Carbon Efficient portfolio has outperformed the S&P 500 by about 24 bps annually since they first invested in the decarbonized index in November 2012, as is shown in Figure 3 below (S&P 500 Carbon Efficient and benchmark up to September 1, 2015), which is in line with the 27bps annual outperformance of the S&P 500 Carbon Efficient Index since January 2010.

[Insert Figure 3]

AP4 has since extended this way of hedging climate risk to its equity holdings in emerging markets.[25] Relying on carbon footprint data provided by *MSCI ESG Research*, AP4 has looked to exclude from the MSCI Custom EM index not only the companies that had the highest GHG emissions but also the worst companies in terms of stranded asset risk. Thereafter, AP4 turned to its Pacific-ex-Japan stock holdings and applied a similar methodology for the construction of its decarbonized portfolio, excluding the companies with the largest reserves and emissions

[24] A 48% reduction level in carbon footprint was achieved when AP4 started investing in 2012.
[25] See Banerjee (2010) for an early analysis of carbon efficient indexes in emerging markets.

intensity, subject to maintaining both sector and country weights in line with its initial index holdings for this region.

More recently AP4, FRR and Amundi have engaged with MSCI to develop another family of decarbonized indices, with a slightly different design. They have constructed the MSCI Global Low Carbon Leaders Index family—based on any of the existing MSCI equity indexes (e.g. MSCI ACWI, MSCI World, and MSCI Europe)—which addresses two dimensions of carbon exposure. It excludes from the indices the worst performers in terms of: i) carbon emissions intensities, and ii) fossil fuel reserves intensities, subject to maintaining a maximum turnover constraint, as well as minimum sector and country. The remaining constituents stocks are then rebalanced so as to minimize TE with the respective benchmarks.[26] The performance of the resulting decarbonized indices based on a back-testing exercise is compared to the MSCI Europe in the table below:

[Insert Table 2]

As can be seen, the Low Carbon Leader Index delivers a remarkable 80bp annualized outperformance of the MSCI Europe from November 2010 to April 2015, with a similar volatility and a 0.75% tracking error.

[26] The criteria for exclusion of a stock from the index are straightforward: First, companies that have the highest emissions intensity (as measured by GHG emissions-to-sales) are excluded with a limit on cumulative sector weighting exclusion of no more than 30%. Second, the largest owners of carbon reserves per dollar of market capitalization are excluded until the carbon reserve intensity of the index is reduced by at least 50%.

A performance attribution analysis performed at the end of July 2015 for the period after the Low Carbon Leaders Index was launched, from November 2014 to May 2015[27] period—during which the outperformance has been particularly high (with an overall 198bps of outperformance)—allows us to distinguish which part of the performance is due to sector allocation (*allocation effect*[28]) and which part is due to stock selection within sectors (*selection effect*[29]). The allocation effect is responsible for 78bps of outperformance, with the underweighting of the energy sector alone responsible for 45bps. More importantly, the effect of screening out the worst GHG performers within a sector is greater than the allocation effect with a 120bps of outperformance. Interestingly, the screening effect was concentrated in two sectors, Materials (102bps) and Utilities (20bps, see Appendix C for a detailed table).

AP4, MSCI, FRR and Amundi have further explored the robustness of these decarbonized indices to other exclusion rules and to higher carbon footprint reductions. They found, first, that there is not much to be gained by allowing for more flexible exclusion criteria that allow for less than 100% exclusion of a high carbon footprint stock. Indeed, the table below compares the performances of a fully "optimized" portfolio, with no strict exclusion of the worst performers, and the portfolio based on the "transparent exclusion rules" outlined above. Whether it is in terms of reduced exposure to carbon or overall tracking error the two portfolios deliver similar results.

[Insert Table 3]

[27] Performance attribution realized on the MSCI Europe Low Carbon Leaders from 11/07/2014 to 05/29/2015.
[28]The "allocation Effect" measures whether the choice of sector allocation led to positive or negative contribution. All else equal, overweighting outperforming sectors lead to positive allocation effect.
[29] The "Selection Effect" measures whether within each sector, the portfolio manager selected the outperforming or underperforming stocks.

Interestingly, however, the two methods for constructing the decarbonized index yield substantial sector by sector differences in tracking error contribution. The contributions to tracking error are very concentrated in two sectors (Materials and Energy) for the fully optimized index. On the contrary, the limit put on total sectorial exclusion in Low Carbon Leaders Index (with transparent rules) spreads the effort across several sectors (see Appendix F for a detailed breakdown of the contribution to specific risk.

5. Conclusion

The decarbonized index investment strategy we analyzed stands on its own as a simple and effective hedging strategy against climate risk for passive long-term institutional investors. But it should also be emphasized that it is an important complement to public climate-change mitigation policies. Governments have so far mostly focused on introducing policies to control or tax GHG emissions and to build broad international agreements for the global implementation of such policies[30] (see Guesnerie and Stern 2012 for a discussion of the pros and cons of cap-and-trade mechanisms versus GHG emission taxes). They have also provided subsidies to solar and wind energy sectors and thereby boosted a small business constituency in support of climate change mitigation policies. In a similar spirit, index decarbonization can help boost support for climate change mitigation policies from a large fraction of the investor community. Moreover, as more and more funds are allocated to such indices, stronger market incentives will materialize inducing the largest corporations in the world—the publicly traded companies—to invest in reductions of GHG emissions. This is all the more attractive that the encouragement of climate risk hedging can have real effects on reducing GHG emissions even before climate change mitigation policies are introduced. The mere expectation that such policies with be introduced will have an impact on the stock prices of the highest GHG emitters, and will reward those investors that have hedged climate risk by holding a decarbonized index. Finally, the very anticipation of the introduction of climate change mitigation policies will create immediate incentives to initiate a transition towards renewable energy.

[30] Notable exceptions include the French government, which has taken a significant lead role ahead of the COP21 to mobilize the financial sector by requiring institutional investors to report on their exposure to climate risk. A handful of central banks have also been instrumental in raising awareness about the possible hazards related to climate change regulations and the potential of mobilizing financial actors. Among them, two significant contributions are the People's Banks of China's "Establishing China's Green Financial System" report and the Bank of England's ongoing prudential review of climate-related risks to the financial sector.

A simple, costless, policy in support of the hedging of climate risk that governments can immediately adopt is to mandate disclosure of the carbon footprint of their state-owned investment arms (public pension funds and sovereign wealth funds). Such a disclosure policy will have several benefits: (i) given that climate change is a financial risk, it provides investors (and citizens) with relevant information on the nature of the risks they are exposed to. Remarkably, some pension funds have already taken this step and pioneered the disclosure of their portfolios' carbon footprint, in particular ERAFP and FRR in France, KPA, the Church of Sweden, the AP funds in Sweden, APG in the Netherlands and GEPF in South Africa; (ii) given that ultimately citizens and pensioners will carry the costs of climate change mitigation, disclosure of their carbon exposure through their pension or sovereign wealth funds helps internalize the externalities of climate change. Indeed, investments by a public pension fund in polluting companies generates a cost carried by its government and trustees and thereby lowers the overall returns on investment. CIC, the Chinese sovereign wealth fund has already made some statements in that direction; and, (iii) disclosure of the carbon footprint of a sovereign wealth fund's portfolio can be a way for sovereign wealth funds of oil and gas exporting countries to bolster risk diversification and hedging of commodity and carbon risk through their portfolio holdings. Indeed, since the basic concept underlying these sovereign wealth funds is to diversify the nature of the assets of the country by extracting the oil and gas under the ground and thereby "transforming" these assets into "above ground" diversifiable financial assets, it makes sense to follow through this policy by diversifying investments held by the sovereign wealth fund away from energy company and other stock holdings that have a large carbon exposure. Interestingly, the French government has just approved a law on energy transition

requiring French institutional investors to disclose their climate impact and carbon risk exposure.[31]

Of course, a more direct way of supporting investment in Low carbon Low TE indices is to push public asset owners and their managers to undertake such investments. Governments could thus play an important role as catalysts to accelerate their mainstream adoption. It is worth mentioning in this respect the interesting precedent of the recent policy of the Shinzō Abe administration in Japan, which has supported the development of the JPX-Nikkei Index 400.What is particularly noteworthy is that the Shinzō Abe administration sees this as an integral part of its "third arrow" to reform Japanese companies. Thus, GPIF—by far the largest Japanese public investor (with more than $1.4tn of AUM)—has since adopted this new index. This example illustrates how the combination of a design of a new index with a policy-making objective together with the adoption of the index by a public asset owner can be a catalyst for change.

In his book, *Finance and the Good Society*, Robert J.Shiller advances a welcome and refreshing perspective of financial economics: "Finance is not about 'making money' per se. It is a 'functional' science in that it exists to support other goals-those of society. The better aligned society's financial institutions are with its goals and ideals, the stronger and more successful the society will be".

It is in this spirit that we have pursued our research on how investors could protect their savings from the momentous risks associated with GHG emissions and their long-term potentially

[31] See article 173 of the "Projet de loi relative à la transition énergétique pour la croissance verte".

devastating effect on climate change. Climate change has mostly and appropriately been the realm of scientists, climatologists, governments and environmental activists. In comparison, there has been relatively little engagement by Finance on this important issue. But, climate change cannot just be ignored by investors and financial markets. The effects of increased temperatures, the increasingly raging weather events it generates, and the climate change mitigation policy responses it could provoke, may have dramatic consequences for the economy and in turn for investment returns. Financial innovation should therefore be explored so that the power of financial markets can be used to address one of the most challenging global threats faced by human kind.

Besides offering investors a hedging tool against the rising risks associated with climate change, a decarbonized index investment strategy can also mobilize financial markets in support of the common good. As a larger and larger fraction of the index investing market is devoted to such decarbonized indices, a virtuous cycle will be activated and enhanced, where the greater awareness of carbon footprints and GHG emissions provides welcome disciplining pressure to reduce CO_2 emissions, and gradually builds an investor constituency in support of climate change mitigation policies. Governments, businesses, technology innovators, and society, in turn, will thus be encouraged to implement changes that accelerate the transition to a renewable energy economy.

Our basic premise and working assumption has been that to engage financial markets with climate change it is advisable to appeal to investor rationality and self-interest. Our argument is simply that even if some investors happen to be climate change skeptics, the uncertainty with

respect to climate change and climate change mitigation policies cannot be waived off as a zero probability risk. Any rational investor with a long-term perspective should thus be concerned about the absence of a market for carbon and the potential market failures that could result from this market incompleteness. A dynamic decarbonized index investment strategy seeks to fill this void and offers an attractive hedging tool even for the climate skeptic.

Finally, the decarbonization approach we have described for equity indices can also be applied to corporate debt indices. So far, the focus in fixed-income markets has been on *green bonds*. However, corporate debt indices—decarbonized along the same lines as equity indices (screening and exclusion based on carbon intensities and fossil fuel reserves maintaining sector neutrality and a low TE)—could be a good complement to *green bonds*. Similarly, low water use indices or other environmental leader indices can be constructed in the same way as our decarbonized indices.

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Tables and Figures

Figure 1

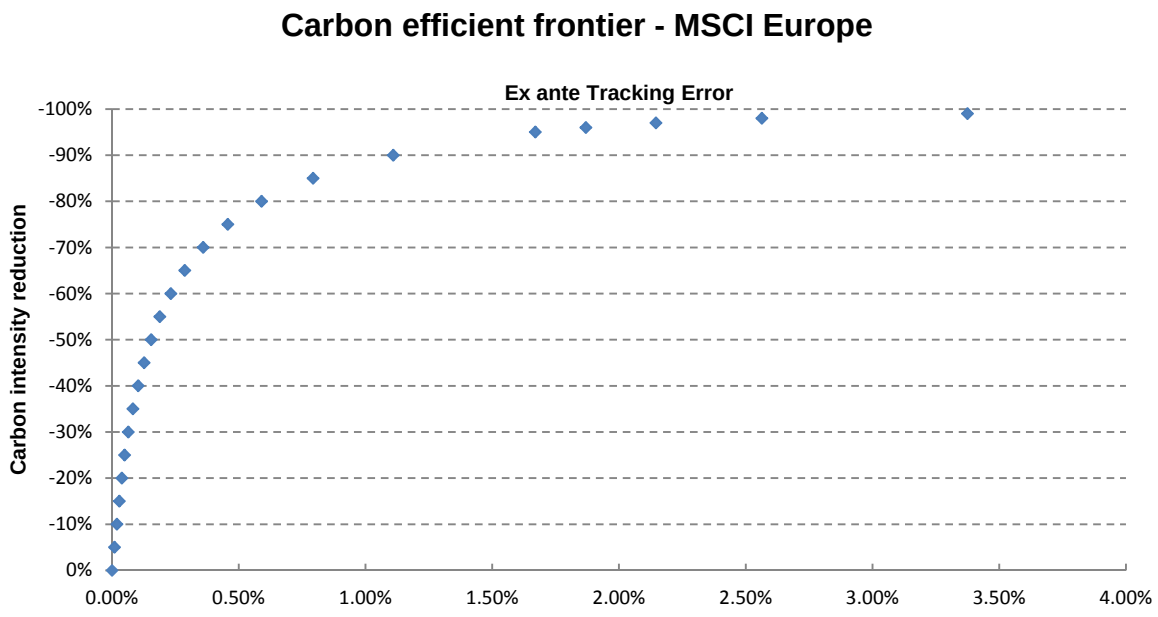


FIGURE 1. Carbon Frontier on MSCI Europe

Source Amundi Quantitative Research as of 06/30/2015

Figure 2

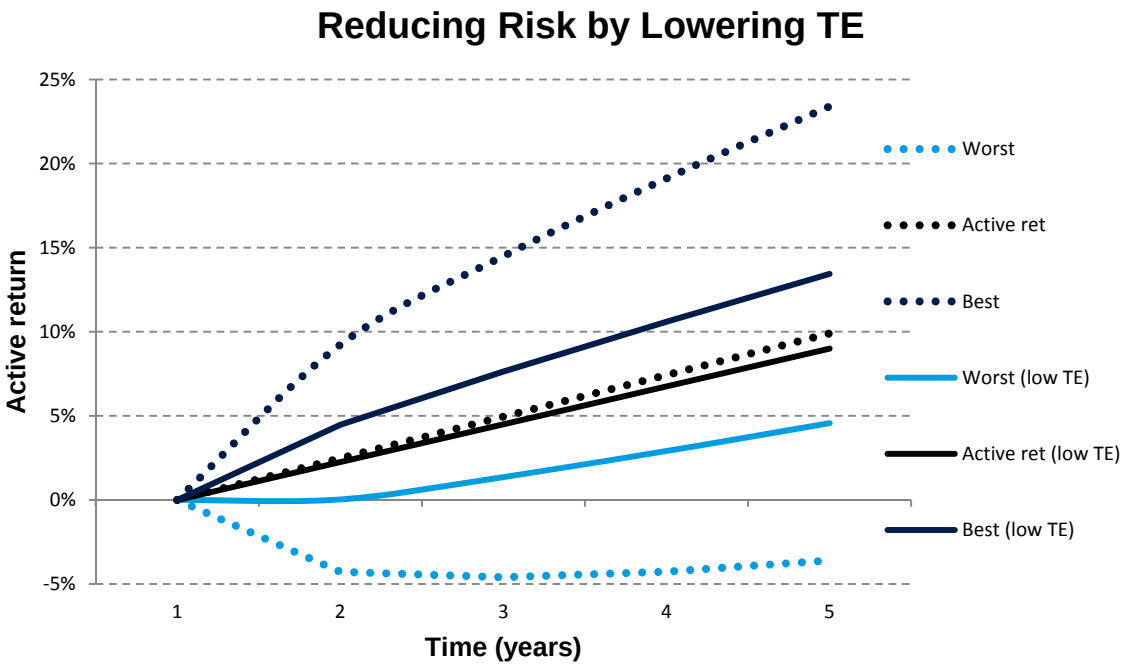


FIGURE 2. Returns and risk with low tracking error
Source Amundi Quantitative Research

Figure 3

FIGURE 3 S&P500 and S&P U.S. Carbon Efficient

Source Amundi, Bloomberg as of 08/31/2015

Table 1

	S&P 500	Nasdaq 100	PP 1	PP 2	PP 3	PP 4	PP 5
Annualized return	4.79%	11.40%	5.02%	-8.72%	2.26%	-8.03%	-1.89%
Annualized volatility	22.3%	23.6%	24.1%	39.3%	30.2%	33.8%	37.3%

Table 1.[32] Pure-play Clean Energy Indices vs. Global Indices
Source Amundi, Bloomberg as of 09/01/2015

[32] Source Amundi, Bloomberg as of 09/01/2015. Table 1 gives the financial returns of several ETFs that track leading Clean Energy Pure Play Indices. Pure Play 1 refers to *Market Vectors* Environmental Services Fund, Pure Play 2 to *Market Vectors* Global Alternative Energy ETF, Pure Play 3 to *PowerShares Cleantech* Portfolio, Pure Play 4 to *PowerShares* Global Clean Energy Portfolio, Pure Play 5 to *First Trust* NASDAQ Clean Edge Green Energy Index Fund and Pure Play 6 to *PowerShares WilderHill* Clean Energy Portfolio. Annualized return and volatility have been calculated using daily data from 01/05/2007 to the liquidation date of Pure Play 1 on 12 November 2014.

Table 2

Key Metrics	MSCI Europe Index	MSCI Europe Low Carbon Leaders Index
Total Return* (%)	12.8	13.7
Total Risk* (%)	11.8	11.8
Return/Risk	1.08	1.17
Sharpe Ratio	1.05	1.14
Active Return* (%)	0	0.9
Tracking Error* (%)	0	0.8
Information Ratio	NA	1.23
Historical Beta	1	0.99
Turnover** (%)	1.8	10.2
Securities excluded	NA	91
Market cap excluded (%)	NA	21.1
Reduction in Carbon Emission Intensity (tCO2/mm USD) (%)	NA	54
Reduction in Carbon Reserves Intensity (tCO2/mm USD) (%)	NA	68

Table 2. Financial performance of transparent rules on MSCI Europe
Source MSCI from 11/30/2010 to 07/31/2015[33]

[33] * Gross returns annualized in EUR for the 11/30/2010 to 07/31/2015 period. ** Annualized one-way index turnover for the 11/30/2010 to 07/31/2015 period. ^ At the May 2015 Index Review.

Table 3

	Optimized Index (Low Carbon Target)	Transparent Rules (Low Carbon Leaders)
Reduction in Carbon Emission Intensity (tCO2/mm USD) (%)	82	**62**
Reduction in Carbon Reserves intensity (tCO2/mm USD) (%)	90	**81**
Tracking Error* (%)	0,9	0,72

Table 3. Carbon and Financial performances of transparent rules on MSCI Europe
Source: MSCI[34]

[34] Back-tests ran over a four year period, from 11/30/2010 to 06/30/2014. * See above.

Appendix

A. Current Context of Climate Legislation :

The United Nations Framework Convention on Climate Change (UNFCCC) coordinates global policy efforts towards the stabilization of GHG concentrations in the atmosphere, with a widely assented policy target for the coming decades of limiting GHG emissions in order to keep average temperatures from rising above 2°C by 2050. However, no concrete policies limiting GHG emissions have yet been agreed that make this target a realistic prospect. To give an idea of what this target entails, scientists estimate that an overall limit in the concentration of CO2 in the atmosphere between 350 parts per million (ppm) and 450 ppm should not be exceeded to have a reasonable prospect of keeping temperatures from rising by less than 2°C (IPCC, 2014). Maintaining CO2 concentrations below that limit, in turn, would require keeping global CO2 emissions below roughly 35 billion tons a year, which is more or less the current rate of emissions (it was 34.5 Gt in 2012 according to the European Commission).

Although the process led by UNFCCC has stalled following the adoption of the Kyoto protocol, a number of countries have taken unilateral steps to limit GHG emissions in their respective jurisdictions. Thus, a very wide array of local regulations, as well as legislation focused on carbon emission limitation and clean energy, have been introduced in the past decade, with for example 490 new regulations put in place in 2012 against only 151 in 2004 and 46 in 1998 (UNEP FI, 2013). Moreover there are promising recent signs of greater urgency concerning climate policies in both the US[35] and China, the two largest economies responsible for a large fraction of global GHG emissions.

If the prospect of a global market for CO_2 emission permits—or even of a global carbon tax—seems far off, the establishment of a national market for CO_2 emission permits in China in the next few years could be a game changer. Indeed, in the U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation, China has pledged to cap its CO_2 emission around 2030, and to increase the non-fossil fuel share of its energy consumption to around 20 percent by 2030[36]. Moreover, following the launch of seven pilot emission-trading schemes (ETS), which are currently in operation, China's National Development and Reform Commission (NDRC) has stated that it aimed to establish a national ETS during its Five-Year Plan (2016-2020).[37]
Yet, despite China's impressive stated climate policy goals, significantly more reductions in CO_2 emissions need to be implemented globally to have an impact on climate change. In particular, the global price of CO_2 emissions must be significantly higher to induce economic agents to

[35] Prominent voices from the business community have recently expressed their concern that the debate over climate policy has become too politicized. Also, in June 2014, the US EPA unveiled an ambitious program, which involves deep cuts in carbon emissions from existing power plants at a 30% national target by 2030, which is equivalent to 730 million tons of carbon emission reductions, or about 2/3 of the nation's passenger vehicles annual emissions.
[36] https://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c.
[37] The inter-regional ETS covering the Beijing, Tianjin and Hebei Provinces was under discussion in May, 2015 at the time of writing. It is also noteworthy that following China's lead there is a movement under way of weaning off existing oil and gas subsidies. According to a recent IMF study by Coady, Parry, Sears and Shang (2015) global subsidies for fossil fuels are estimated to represent a total of $333 billion for 2015.

reduce their reliance on fossil fuels, or to make Carbon Capture and Storage worthwhile (current estimates are that a minimum carbon price of about $25-30 per ton of CO_2e is required to cover the cost of Carbon Capture[38]). Therefore, with the continued rise in global temperatures and the greater and greater urgency of strong climate mitigation policies in the coming years it is possible that policy makers will at last come to the realization that they have little choice but to act by implementing radical climate policies resulting in a steep rise in the price of carbon. On top of national governments mobilization, major religious authorities have recently step up to express their concern on climate change and urge both governments and civil society to act.[39]

B. Stranded Assets Risk:

The notion of stranded assets was first introduced by the Carbon Tracker Initiative (Carbon Tracker 2011, 2013[40]) and Generation Investment (2013). It refers to the possibility that not all known oil and gas reserves are exploitable should the planet reach the peak of sustainable concentrations in the atmosphere before all oil and gas reserves have been exhausted. A plausible back-of-the-envelope calculation goes as follows: Earth's proven fossil fuel reserves amount to approximately 2,800 Gt of CO_2 emissions (Carbon Tracker, 2011). But to maintain the objective of no more warming than 2°C by 2050 (with at least a 50% chance) then the maximum amount of allowable emissions is roughly half, or 1,400 Gt of CO_2. In other words, oil companies' usable proven reserves are only about ½ of reported reserves. Responding to a shareholder resolution, ExxonMobil published for the first time ever a report in 2014[41] describing how it assesses the risk with respect to stranded assets. Much of the report is an exercise in minimizing shareholders and analysts' concerns on stranded asset risks by pointing to the International Energy Agency's projections on growing energy demand without competitive substitutes leading to higher fossil fuel prices. Nonetheless, it cannot entirely be ruled out that a growing fraction of proven reserves will be seen by investors to be unexploitable because they are simply too costly, be it because cheap clean and reliable substitutes emerge in the form of competitive clean energy, or because climate mitigation policies become an increasingly binding reality (or, more likely, both).

C. Carbon Data:

Nature of carbon emissions and carbon reserves data: Carbon emissions and carbon reserves relate to a wide array of greenhouse gases (GHG) and hydrocarbon reserves. The standard unit of measurement is the metric ton of carbon dioxide equivalent (MtCO2e), usually abbreviated to tons of carbon. Regarding GHG emissions, the most widely used international carbon accounting tool for governments and businesses is the GHG protocol. This protocol serves as the foundation for almost every GHG standard in the world, notably the International Organization for

[38] The current price level is far below $30, with average carbon prices ranging from RMB23.95 to RMB77.00/t CO_2e (as of 05/20/2014) in China, average EUR6.50/t (as of 08/31//2014) in Europe, and $12 in the different regional initiatives in North America.

[39] Pope Francis' *Laudato Si'* encyclical published in May 2015; Muslim scholars' *Islamic Declaration on Global Climate Change* published in August 2015 and U.S. Rabbis' *Rabinic Letter on the Climate Crisis* released in May 2015 show that climate change has become a shared concern among religious authorities.

[40] See Kepler (2014) for a recent study on the risk of stranded assets.

[41] See "Energy and Carbon – Managing the Risks", ExxonMobil (2014); (Shell followed with an "Open Letter on Stranded-Asset Risk" in May 2014).

Standardization (ISO) and Climate Registry. Corporate Users include BP, Shell, General Motors, GE, AEG, Johnson & Johnson, Lafarge, Tata, etc. Non-Corporate Users include Trading schemes (EU ETS, UK ETS, Chicago Climate Exchange), NGOs (CDP, WWF, Global Reporting Initiative), Government agencies in China, the U.S., U.S. states, Canada, Australia, Mexico etc.

According to the protocol, GHG emissions are divided into three scopes: Scope 1 relates to direct GHG emissions, that is, emissions which occur from sources owned or controlled by the company (e.g. emissions from fossil-fuels burned on site or leased-vehicles). Scope 2 emissions are GHG indirect emissions resulting from the purchase of electricity, heating and cooling or steam generated off site but purchased by the entity. Scope 3 emissions encompass indirect emissions from sources not owned or directly controlled but related to the entity's activities (e.g. employee travel and commuting, vendor supply chain, etc.). It is obvious that Scope 3 emissions represent the largest GHG impact for many companies, be it in upstream activities (e.g. consumer electronics) or downstream activities (automotive industry). However, Scope 3 emissions reporting still lack standardization and the reporting level remains low (according to Trucost, in 2013, only 180 of the Fortune 500 companies reported on some portion of their supply chain).

The estimation of CO_2 equivalent of carbon reserves is a three-step process, which involves first the classification and estimation of hydrocarbon reserves, and then translates these reserves into CO_2 emissions. The data considered for estimation of fossil fuel reserves and stranded assets are most of the time proved reserves (90% probability that at least the actual reserves will exceed the estimated proved reserves). Those data are publicly available and must be disclosed in company's reports. Once the proven reserves are estimated in volume or mass, two steps are still required. First, the calorific value of total fossil fuel reserves needs to be estimated, and then calorific value needs to be translated into carbon reserves using a carbon intensity table.

Carbon data providers: At the two ends of the spectrum of carbon data providers, we find entities that simply aggregate data provided directly by companies or that are publicly available, and entities that only use their internal models to estimate carbon emissions or reserves.

Corporations themselves are the primary providers of carbon data, via two main channels: (i) CSR reports for 37% of the world's large companies (with market cap exceeding $2bn.), which disclose completely their GHG emission information; (ii) CDP, which provides the largest global carbon related database, in partnership with Bloomberg, MSCI ESG, Trucost, etc. Companies respond to Annual Information Request Forms made by CDP for climate change related information collection, and the number of respondents has increased from 235 in 2003 to 2132 in 2011. Financial data vendors such as Bloomberg generally provide datasets with sources from CDP, CSR report, and other manually searched ones. The heterogeneity of sources explains the discrepancy that can sometimes be found in carbon footprint measurements.

D. Tracking Error minimization with a Multi-factor Model of Risk:

D.1 Ex ante and ex post Tracking Error:

Index managers usually seek a very low tracking error, but some of them may also seek higher returns by optimizing index replication (tax optimization, management of changes in index composition, management of takeover bids, etc.). For an index manager, there is a trade-off between the goal of minimizing tracking error (TE) and maximizing return. Two different measures of tracking error are used by portfolio managers: (i) Ex post TE is the measure of the volatility of the realized active return deviations from the benchmark and (ii) Ex ante TE is an estimation (or prediction) based on an estimated multi-factor model.

Ex-ante TE is a function of portfolio weights, benchmark weights, the volatility of stocks and correlations across assets. Thus, in order to estimate portfolio risk once portfolio weights and benchmark weights are given, we need the covariance matrix of security returns. One can estimate such a covariance matrix using historical data of security returns, but this method is burdensome and prone to estimation error (spurious correlations).

An alternative method is to use a multi-factor model. We rely on the widely used BARRA Multiple-Factor Model (MFM)[42], which decomposes the return of an individual stock as the weighted sum of common factor returns and an idiosyncratic return as follows:

$$r_i = \beta_{country\ i} f_{country\ i} + \beta_{sector\ i} f_{sector\ i} + \beta_{size\ i} f_{size\ i} + \cdots + u_i$$

$$r_i = \sum_{j=1}^{J} \beta_{ji} \tilde{f}_j + u_i$$

$$\begin{bmatrix} r_1 \\ \vdots \\ r_n \end{bmatrix} = \begin{bmatrix} \beta_{11} & \cdots & \beta_{1k} \\ \vdots & \ddots & \vdots \\ \beta_{nk} & \cdots & \beta_{nn} \end{bmatrix} \begin{bmatrix} f_1 \\ \vdots \\ f_J \end{bmatrix} + \begin{bmatrix} u_1 \\ \vdots \\ u_n \end{bmatrix}$$

$$r = \beta f + u$$

Where β_{ji} is the factor loading for security *i* on common factor *j*, f_j is the common factor return, and u_i is the part of return that cannot be explained by common factors.

D.2 Estimating factor returns:

Common factors used by BARRA include industries, styles (Size, Value, Momentum and volatility), and currencies (68 factors are used for the Multiple-Horizon U.S. Equity model).
Common factor returns are estimated using monthly stock returns. The times series of factor returns are then used to generate factor variances and covariances in the covariance matrix:

[42] See MSCI Barra Risk Model Handbook (2007) for a thorough review of Barra equity risk modeling.

$$\begin{bmatrix} Var\ (f_1) & \cdots & Cov\ (f_1, f_k) \\ \vdots & \ddots & \vdots \\ Cov\ (f_k, f_1) & \cdots & Var\ (f_k) \end{bmatrix}$$

In order to capture variance and covariance dynamics and improve the predictive power of the model, BARRA uses an exponential weighting scheme that gives more wright to recent data, so that—on average—the last two to three years of data represent 50% of the available information ("half-life").

D.3 From factor returns to risk estimation:

Similarly to components of returns, components of risks can be divided into common factor sources and security specific risk:

$$Var\ (total\ \ risk) = Var\ (common\ factor\ risk) + Var\ (active\ specific\ risk)$$

And the multifactor equation becomes:

$$Var(r) = Var(\beta f + u)$$

$$Var(r) = \beta \Omega_f \beta' + \Delta$$

Where β is the matrix of factor exposures, β' the transposed matrix, Ω is the variance-covariance matrix for the K factors, and Δ is the diagonal matrix of specific risk variances.

The volatility σ_p of any portfolio *p,* represented by a vector of portfolio weights W_p is thus:

$$\sigma_p = \sqrt{W_p(\beta \Omega_f \beta' + \Delta) W_p'}$$

D.4 TE minimization:

In the case of tracking error minimization, the objective function is the ex-ante tracking error and constraints can range from turnover limits to re-weighting rules with or without active weights constraints, etc.

Example of a *Low Carbon Low TE Multi-Utilities Fund*:

- Let uss consider a reference universe of 10 constituents, let say the Multi-Utilities industry group in the Utilities sector in a large economic zone;
- Let us assign to each constituent an index weight that is equal to $\frac{Mkt\ Cap\ (i)}{Total\ Mkt\ Cap}$ in order to obtain a market cap-weighted index and let $(w_1^b, \cdots, w_{10}^b)$ be the constituent stocks' weights;

- We rank the constituents according to their carbon intensity (e.g. CO_2e / GWh) and then adopt the following constraint (rule):

$$\begin{pmatrix} w_1^b \\ w_2^b \\ \vdots \\ w_{10}^b \end{pmatrix} => \begin{pmatrix} 0 \\ w_2 \\ \vdots \\ w_{10} \end{pmatrix}$$

- In other words, the optimal portfolio $(0, w_2, \cdots, w_{10})$ will be the result of the minimization of the following objective function:

$$Min\left\{\sqrt{(W^p - W^b)'\left(\beta\Omega_f\beta' + \Delta\ \right)(W^P - W^b)}\right\}$$

Subject to:

$$\forall i = 1, \cdots, 10\ ;\ 0 \leq w_i$$

$$i = 1\ ;\ w_1 = 0$$

Where $\left(\mathrm{W}^{\mathrm{p}} - \mathrm{W}^{\mathrm{b}}\right)$ represent the active weights of the portfolio with regards to the benchmark, Ω_{f} the variance-covariance matrix of factors, β the matrix of factor exposure and Δ the diagonal matrix of specific risk variances.

Barra uses an optimization algorithm to minimize the TE under the new constraint of excluding stock n.1. It will select active weights depending on the factor loading of each security and the covariance between each factor in order to have a new portfolio that closely tracks the reference portfolio.

E. Performance Attribution of the MSCI Low Carbon Leader Europe Index:

Performance Attribution

MSCI Europe Low Carbon Leaders vs. MSCI Europe

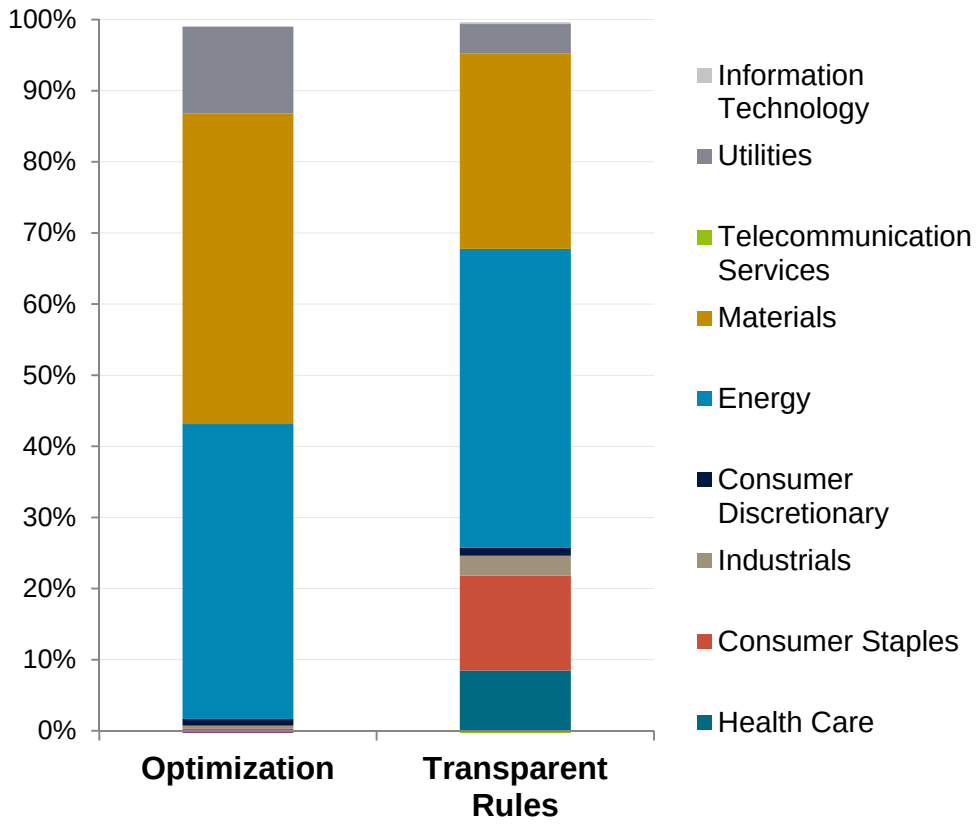
11/07/2014 to 7/31/2015

Euro

	MSCI Europe Low Carbon Leaders			MSCI Europe			Attribution Analysis		
GICS Sector	Port. Average Weight	Port. Total Return	Port. Contrib. To Return	Bench. Average Weight	Bench. Total Return	Bench. Contrib. To Return	Allocation Effect	Selection + Interaction	Total Effect
Total	100.00	22.27	22.27	100.00	20.29	20.29	0.78	1.20	1.98
Consumer Discretionary	11.96	29.90	3.43	10.81	30.14	3.12	0.11	-0.02	0.09
Consumer Staples	11.58	24.57	2.90	13.72	24.06	3.38	-0.06	0.05	-0.02
Energy	5.61	-7.26	-0.49	7.49	-2.75	-0.28	0.45	-0.27	0.18
Financials	23.76	21.47	4.94	21.92	21.05	4.40	0.02	0.10	0.12
Health Care	13.38	27.31	3.59	13.75	26.68	3.60	-0.01	0.06	0.05
Industrials	12.96	20.11	2.65	11.08	19.68	2.21	0.00	0.05	0.05
Information Technology	3.80	25.52	1.02	3.45	22.74	0.78	0.06	0.09	0.15
Materials	6.12	25.64	1.54	7.53	10.09	0.85	0.14	0.88	1.02
Telecommunication Services	6.01	30.92	1.81	5.20	30.90	1.53	0.08	0.01	0.09
Utilities	3.87	11.16	0.45	3.97	7.07	0.28	0.03	0.17	0.20

Source Amundi Quantitative Research

F. Percentage contribution to specific risk per sector:



Source Amundi Quantitative Research, computed on MSCI Europe as of 31/05/2014

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