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Research article

Do clean energy (equity) investments add value to a portfolio?

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Abstract: Investment in renewable energy needs to increase significantly to address climate change. Large institutional investors with huge asset bases, such as pension funds, mutual funds, insurance companies, and sovereign wealth funds, can be a prime potential source of capital for renewable energy. One way to ensure increased investment commitment from such investors is for them to treat clean energy as a separate asset class in their portfolios. Through this paper, our aim is to present initial insights into the potential effect the addition of clean energy listed equity as a separate asset class can have on existing portfolios. We focus on the value of listed renewable energy equity in a static portfolio optimization problem. Our main finding is that treating renewable energy listed equity as a separate asset class within an investor's portfolio does not appear to add value to that portfolio. On one hand, this may reflect the need for applying more sophisticated techniques to show value. On the other hand, it may also imply that governments, policy makers, and regulators must keep working to ensure the clean energy sector is conducive to mainstream investment.

Keywords: renewable energy; listed equity; portfolio value; optimization; institutional investment

JEL Codes: G11, G18, G23, G32

1. Introduction

1.1. Background

To address climate change, energy generation has to transition away from fossil fuels and towards clean energy sources. In fact, according to the International Energy Agency (IEA), to limit global temperature change to within Two Degrees Celsius (2C), there is a requirement of $2.3 trillion/year of renewable energy investment through 2040 (IEA, 2016). However, historical investments are approximately $0.75 trillion/year (IEA, 2016), or less than one-third of the required annual amount.

At this rate, targets related to achieving renewable energy capacity installation will clearly not be met, implying that temperature changes are likely to breach the 2C targets. We need significantly more investments in renewable energy—$1.5 trillion/year—from existing as well as additional sources. In the latter category, institutional investors show a lot of promise.

Large institutional investors with huge asset bases, such as pension funds, mutual funds, insurance companies, and sovereign wealth funds, can be a prime source of capital for renewable energy. The total assets under management of institutional investors exceed $100 trillion globally, with around $3.4 trillion available to invest annually (Reicher et al., 2017). The question then becomes: How can these investors be incentivized to invest in clean energy?

One way to ensure increased investment commitment from such investors is for them to treat clean energy as a separate asset class in their portfolios, i.e. at a strategic level (Blake et al., 2015; Deutsche Bank, 2012). Doing so would ensure a minimum percentage allocation of the total portfolio to the clean energy sector, thus increasing overall investment in renewable energy by a significant amount. On the other hand, in absence of evidence that clean energy as a separate asset class adds value at a strategic asset allocation level, this sector would continue to be subsumed under the broader alternative investments at the tactical asset allocation level, which may obfuscate the sector's investment potential and thus limit actual investments into the sector.

1.2. Previous work

At a high level, while there has been extensive research on the relationship between a firm's environmental and financial performance, the empirical results have been inconclusive (Orlitzky et al., 2003; Margolis et al., 2009; Fulton et al., 2012; Mercer, 2009). While some studies (Hart and Ahuja, 1996; Russo and Fouts, 1997; Dowell et al., 2000; King et al., 2002; Konar and Cohen, 2001), suggest a positive relationship, other studies find a negative or insignificant relationship (Filbeck and Gorman, 2004; Telle, 2006; Ziegler and Seijas Nogareda, 2009).

Closer to our work, analysis to assess the value of a new asset class in investor portfolios has been done for infrastructure, which includes clean energy. On one hand, some studies have questioned the claim that listed infrastructure as an asset class adds value to a portfolio (Blanc-Brude et al., 2017; Rothballer and Kaserer, 2012; Idzorek and Armstrong, 2009). Many studies, including academic ones on listed infrastructure (Newell et al, 2011; Bird et al, 2014; Bianchi et al, 2014), have validated that treating infrastructure as a separate asset class does add value to existing portfolios, for both listed infrastructure (Credit Suisse, 2010; IVG Research, 2012; Deutsche Bank, 2013; IEEFA 2017) and unlisted infrastructure (Cremers, 2013; BlackRock, 2014).

Our motivation was to perform similar analyses for the clean energy sector to assess whether or not an economic case can be built for institutional investors to assign a greater proportion of capital to the sector. There is only limited research focusing solely on the value of clean energy as an asset class in an investor portfolio. While Ahmad et al. (2018) presents an analysis of how investments in clean energy can be hedge, they do not examine the value of clean energy investments in portfolios. The closest to our work is Monaca et al. (2018), who examine value of clean energy exchange traded funds as well as

YieldCos and find minimal diversification benefits. Our research provides complementary analysis to Monaca et al. (2018) by examining broader listed equity indices.

1.3. This study

Through this discussion paper, our aim is to present initial insights on the potential effects of adding clean energy listed equity as a separate asset class on existing portfolios. While we recognize there can be more nuanced data as well as more sophisticated techniques (BlackRock, 2014), in this paper we have decided to focus on the lowest hanging fruit from both data and methods perspectives. That is, we focus on the value of (publicly available) listed clean energy equity in a (first order) static portfolio optimization problem.[1]

To assess the value of clean energy as a separate asset class, we developed two hypotheses—which were thereafter tested out. The results of the hypotheses testing would ascertain whether or not treating clean energy as a separate asset class adds or erodes value to a base portfolio. In this paper, since we are primarily focused on publicly-traded clean energy equity, unless mentioned otherwise, a discussion of clean energy as an asset class by default refers to publicly-traded clean energy equity.

The development of the two hypotheses is predicated on the Modern Portfolio Theory (Markovitz, 1952), which assumes that investors will choose to invest in portfolios that offer higher expected risk-adjusted returns. This may mean, for a target level of risk, portfolios that maximize return; or for a target level of return, portfolios that minimize risk. The two hypotheses are as follows:

1.3.1. Does treating clean energy as a separate asset class add value to existing portfolios?

As a first step, we check for a potential positive impact. For the underlying hypothesis to be true, the addition of clean energy to a portfolio would increase the risk-return profile of the portfolio. That is, addition of clean energy would either lower the risk for the same level of returns or the increase the returns for the same level of risk.

In case this hypothesis turns out to be true, then a case can be made for institutional investors to invest more heavily into the clean energy sector. Such a scenario may warrant a further analysis to explore investment strategies that can add the most value to existing portfolios. And, in case this hypothesis (i.e., a positive impact) turns out to be false, then our next step is to check for a potential negative impact.

1.3.2. Does treating clean energy as a separate asset class refrain from eroding value to existing portfolios?

In case the underlying hypothesis turns out to be true, then a case can be made to replace one of the existing asset classes in a portfolio with clean energy. We can argue that given the positive externalities of the clean energy sector (such as lower environmental damage, reduced public health

[1] More nuanced analysis, which we recommend for future work, may include broader datasets such as unlisted renewable equity as well as more sophisticated techniques such as liability driven, simulation based optimization (BlackRock, 2014). For the former, EDHEC (2018) describes a methodology that is currently being used to create unlisted infrastructure indices.

spend) compared to potential negative externalities of other sectors (higher environmental damage, increased public health spend), investors should prefer to invest in the former, when both offer similar risk-reward profiles.

In case these underlying hypothesis turns out to be false, then there is no real economic incentive for institutional investors to treat clean energy as a separate asset class. This means the governments, policy makers, and regulators need to increase efforts to make the clean energy sector more conducive for investment. This can be done through better policy formulation, more efficient subsidies for clean energy or reduced subsidies to the fossil-fuel industry, facilitating more sector-specific information to the market, developing risk mitigation instruments to mobilize private investments, among others.

1.4. Key takeaway

While the genesis of this study was the hope that we would find portfolio value of renewable energy investments quickly, our main finding is that treating renewable energy listed equity as a separate asset class within an investor's portfolio does not appear to add value to that portfolio. On one hand, this may reflect the need for applying more sophisticated techniques to show value. On the other hand, it may also imply that clean energy does not yet offer the requisite adjusted returns, and that governments, policy makers, and regulators must keep working to ensure that the sector is conducive to mainstream investment.

2. Methods and data

Before we explicate on the results and the corresponding conclusions, we will briefly describe the methodology used for performing these analyses.

2.1. Selecting a base portfolio and a clean energy asset class

For our study, we first chose a base portfolio consisting of equities, bonds, private equity and real estate investment trusts (REITs). The base portfolio does not have a fixed protocol and can include or exclude certain asset classes; however, the asset classes we chose are fairly common in the portfolio industry (Little, 2017). The scope of these asset classes was global in nature wherever possible; otherwise data for only the U.S. market was selected (Davidow, 2018).

We used the daily returns[2] of following indices as proxies for the aforementioned asset classes:

a) Equities: S&P Global 1200
b) Bonds: S&P U.S. Aggregate Bond Index
c) REITs: S&P United States REIT (or S&P US REITs)
d) Private Equity: S&P Listed Private Equity Index (or S&P Listed PE)

[2] While there can be a debate about the frequency of data, daily, weekly, and monthly are commonly used frequencies (Damodaran, 2018); we choose daily to provide the maximum granularity.

For the clean energy index, we chose S&P Clean Energy Index, since it covers companies throughout the value chain of the clean energy industry,[3] from R&D firms to developer companies (S&P Indices, 2018). Moreover, the scope of the companies forming the index is global in nature, which is in line with the base portfolio chosen.

2.2. Collecting relevant data

Data was collected for the aforementioned indices for the preceding 10 years, 5 years, and 3 years ending in May 2017. We wanted to explore the trends for multiple time durations to add a layer of certainty to our findings and to make sure one-time effects did not distort results, and therefore decided to perform our analyses for different tenures. Once the data was collected, the indices were normalized to a base of 100 to ensure they were comparable on an apples-to-apples basis.

2.3. Assessing the value add of clean energy

After normalizing the indices, we used a technique known as Mean-Variance Optimization (MVO) to assess the value add of clean energy (Markowitz, 1952). MVO is a quantitative technique that allows one to allocate different asset classes in a portfolio in the most efficient manner (Merton, 1972; Investopedia, 2018). MVO is predicated on the Modern Portfolio Theory, which seeks to maximize a portfolio's expected return for a given level of risk.

In other words, for a chosen risk level, MVO will allocate the proportion of different asset classes in a manner resulting in the highest level of portfolio expected return[4]. Equivalently, this may mean minimizing risk for a target level of return, or simply maximizing risk-adjusted returns directly.

Measurement of portfolio performance:

For a N-asset portfolio, the expected portfolio return is computed as the following (Rosenthal, 2006):
Equation 1: Measurement of portfolio performance

$$E[Rp] = \sum_{i=1}^{n} Wi * \mathrm{E[Ri]} \quad (1)$$

where
$E[Rp]$ = the expected return on the portfolio,
n = the number of stocks in the portfolio,
Wi = the proportion of the portfolio invested in asset i, and
E[Ri] = the expected return on asset i.

Similarly, for a N-asset portfolio, the portfolio's expected risk, as measured by its standard deviation, is computed as the following:

[3] This nuance is important, given that the clean energy index includes companies across the entire value chain, including panel and turbine manufacturing, which are typically not infrastructure projects. That is, the index is not simply renewable energy generation companies. A more nuanced analysis may look at only the latter, given that renewable energy generation projects are infrastructure projects which may provide certain value in a portfolio (IVG Research, 2012).

[4] Note that we are focused on straightforward MVO, without sophisticated approaches, such as ones used in Black and Litterman (1992), or in IVG Research (2012)

Equation 2: Expected risk of a N-asset portfolio

$$\sigma p = \left(\sum_{i=1}^{N} Wi^2 \sigma^2(ki) + \sum_{i=1}^{N} \sum_{i \neq j}^{N} \mathrm{WiWjR(ki,kj)\sigma(ki)\sigma(kj)} \right)^{(1/2)} \tag{2}$$

where $\mathrm{R(ki, kj)}$ is the correlation coefficient of returns of ith asset and jth asset, $\sigma(\mathrm{ki})$ is the standard deviation of return of ith asset, and $\sigma(\mathrm{kj})$ is the standard deviation of return of jth asset (Rosenthal, 2006; Smirnov, 2018).

We focused on maximization of risk-adjusted returns directly, given that this incorporates both returns and risks in the objective function. We used Sharpe ratio to measure the risk-adjusted expected returns of a portfolio. Sharpe ratio is a commonly used metric to assess the performance of an investment, by adjusting for the risk (Lioudis, 2017). Mathematically, it is defined as the excess return per unit of risk undertaken:
Equation 3: Sharpe Ratio

$$Sp = (Rp - Rf)/Op \tag{3}$$

where
Rp = Portfolio's expected return
Rf = Risk-free rate, and
Op = Portfolio's expected risk (measured by portfolio standard deviation)

For the sake of convenience, we have simply used total expected return (while also using the shorthand $\mathrm{R} = \mathrm{E[R]}$) per unit risk undertaken (O) as a proxy for Sharpe Ratio.

Controlled Experiment—With and Without Clean Energy:

Once we had the data set ready, we carried out two independent analyses: in the first instance, we performed MVO only on the base portfolio; and, in the second instance, we performed the optimization by including the clean energy asset class. The results were then compared to assess whether adding clean energy as a separate class enhances the risk-return metrics of the portfolio.

We performed the above MVO steps under two scenarios—unconstrained optimization as well as constrained optimization (We provide additional background on MVO in the Annexure, including basic steps on how to perform the MVO):

2.3.1. Unconstrained optimization

In an unconstrained scenario, there are no restrictions on the investment strategy. That is, there is no upper or lower cap on how much each asset class can be allocated or limits on the expected risk undertaken. Asset classes would be allocated in a manner that provides the highest expected returns per unit of risk undertaken. That is, the optimization problem is that specific allocation distribution when the Sharpe ratio, i.e. $Sp = Rp/O$p is maximized with $\Sigma wi = 1$and no other constraints are imposed.

2.3.2. Constrained optimization

A constrained scenario has user-defined limitations, such as an upper or a lower cap on each asset class' allocation, restrictions on short-selling, a pre-defined range for expected risk to be undertaken, and so forth. Constraints are commonly deployed in the portfolio industry to add a

degree of predictability to investment portfolios and to keep the investment strategy aligned with the overall mandate. That is, the optimization problem is as follows:
Equation 4: Maximized Sharpe Ratio

$$\text{Maximize } Sp = Rp/\sigma\text{p} \tag{4}$$

when $\Sigma wi = 1$, under constraints such as Rp = min (Ri) or σp = max(σi)
Note: these constraints are user-defined and vary on a case by case basis.

3. Results

We first carried out MVO for 10-year data; thereafter we repeated the exercise for the 5-year and 3-year data, to explore whether the results were sensitive to the duration of the tenure. Within each time horizon, we examined unconstrained as well as constrained optimizations.

The results of the analyses would help to verify or repudiate the hypotheses we set out to test, as defined in Section 1. We first focus on describing each of the results (Sections 3.1 and 3.2), followed by a summary discussion of what these results mean for the hypothesis (Section 3.3). Section 3.1 provides results for 10-year data, whereas Section 0 provides results for 5 and 3-year data.

3.1. 10-year data

To add rigor to our analysis, we performed the MVO for both the unconstrained (Section 3.1.1) and constrained scenarios (Section 3.1.2), for Hypothesis I (Sections 3.1.1.1 and 3.1.2.1) as well as Hypothesis II (Sections 3.1.1.2 and 3.1.2.2).

3.1.1 Unconstrained scenario

An unconstrained model is one in which there is no restriction on the proportion of total portfolio that can be allocated to a single asset class. That is, any asset class can be between 0 and 100% so long as the portfolio is optimized as per the inputs.

We first performed the MVO for a base portfolio without the clean energy to gauge the level of allocation for each asset class that would optimize portfolio's expected performance (Table 1).

Table 1 suggests that when the selected bond, equity, REIT and PE indices are assigned weights of 88.4%, 10.2%, 1.4% and 0% respectively[5], the portfolio's expected performance will be optimized, as measured by Sharpe Ratio. For all other allocations, the portfolio Sharpe ratio (Sp) will be lower than the value of 0.0784.

[5] This analysis indicates that an optimal portfolio does not include private equity either.

Table 1. Portfolio Optimization for 10-year data (unconstrained).

Portfolio Weight	
Constraining Variable	None
S&P US Bonds	88.4%
S&P US REITs	1.4%
S&P Listed PE	0%
S&P Global 1200 equity	10.2%
Total (Check)	*100%*
Rp (Portfolio Expected Return)	0.017%
Ơp (Portfolio Risk)	0.216%
Max Sharpe Ratio (Sp = Rp/Ơp)	0.0784

3.1.1.1. Addition of Clean energy as a new asset class (Question/Hypothesis I)

We then performed a similar analysis while adding clean energy as a new asset class. According to optimization results in Table 2, the total allocation to the clean energy index came out to be zero, implying that, based on MVO, clean energy does not add value to the base portfolio. That is, we do not find evidence to support Hypothesis I.

Table 2. Portfolio Optimization for 10-year data (unconstrained) with clean energy.

Portfolio Weights	
Constraining Variable	None
S&P US Bonds	88.4%
S&P US REITs	1.4%
S&P Listed PE	0%
S&P Global 1200	10.2%
S&P Global Clean Energy	**0.0%**
Total (Check)	***100%***
Rp (Portfolio Expected Return)	0.013%
Ơp (Portfolio Risk)	0.165%
Max Sp (= Rp/Ơp)	0.0784

3.1.1.2. Replacing an existing asset class with clean energy (Question/Hypothesis II)

To set out hypothesis II, we replaced an existing asset class with the clean energy index. If the new portfolio's Sharpe ratio improved, it implies that clean energy adds value; on the other hand, if the Sharpe ratio declines, then such a move erodes value, and renders hypothesis II as false.

To replace an existing assets class by renewable energy, we use an indirect approach, where we make the allocation of the replaced class zero. For instance, if bonds are getting replaced in the base portfolio (Table 3), then the allocation of bonds are mandatorily zero. This would allow selection of clean energy in the portfolio. The expected performance of the modified portfolio, when optimized, can be compared with that of the base portfolio to assess whether replacing an existing asset class will result in any value addition.

Table 3. Portfolio Sharpe ratios after replacing an existing asset class.

Portfolio Weights					
	Base	Replaced asset class			
	Portfolio	S&P Bonds	S&P REITs	S&P Listed PE	S&P Global Equities
Constraining Variable	None	None	None	None	None
S&P Clean Energy	-	0.0%	0%	0%	0.0%
S&P Bonds	88.4%	-	88.0%	88.4%	92.7%
S&P REIT	1.4%	19.7%	-	1.4%	2.9%
S&P Listed PE	0%	0.0%	0%	-	4.3%
S&P Global Equities	10.2%	80.3%	12.0%	10.2%	-
Total (Check)	*100%*	*100%*	*100%*	*100%*	*100%*
Rp (Portfolio Return)	0.017%	0.028%	0.017%	0.017%	0.017%
σp (Portfolio Risk)	0.216%	1.253%	0.215%	0.216%	0.225%
Sharpe Ratio (Rp/σp)	0.0784	0.0223	0.0780	0.0784	0.0743

From the analysis, it is clear that replacing one of the existing asset classes in the base portfolio does not improve the portfolio's expected performance. That is, we do not find evidence to support Hypothesis II. In fact, doing so erodes the value of the portfolio, as can be seen from declines in respective Sharpe ratios relative to the Sharpe ratio of the base portfolio. Moreover, as can be seen from Table 3, clean energy is assigned a weight of zero in each case. That is, had clean energy been allocated a value more than 0, the portfolio's expected performance may have declined further.

3.1.2. Constrained scenario

Our next step was to perform portfolio optimization using certain constraints that are commonly deployed in the portfolio industry (Muller, 2005). Constraints add a degree of predictability to investment portfolios and keep the investment strategy aligned with the overall mandate.

Before we set out to optimize the portfolio, we tested out the risk-return metrics for individual asset classes.

Table 4. Risk-return metrics for individual asset classes (10-year data).

	R (Return)	σ (Volatility)	*Sharpe Ratio (μ/σ)*
S&P Clean Energy	−0.034%	2.041%	*−0.017*
S&P Bonds	0.016%	0.250%	*0.063*
S&P REIT	0.043%	2.297%	*0.019*
S&P Listed PE	0.021%	1.651%	*0.013*
S&P Global Equities	0.024%	1.130%	*0.021*

Thus, based on the expected returns and risks of individual asset classes, we devised three constraints (highlighted in Exhibit 5):

i) Constraint 1 (minimum return): Portfolio's expected return should exceed or be equal to highest expected return of any individual asset class (Rp ≥ 0.043%).

ii) Constraint 2 (maximum risk): Portfolio's expected risk should be less than or equal to the lowest expected risk of any individual asset class (σp ≤ 0.250%).

iii) Constraint 3 (minimum Sharpe ratio): Portfolio's Sharpe ratio should be higher than or equal to the highest Sharpe ratio of any individual asset class (Portfolio Sharpe ratio or Sp ≥ 0.063).

Similar to what we did for the unconstrained scenario, we first performed MVO on the base portfolio without the clean energy index:

Table 5. Portfolio Optimization for 10-year data under different constrained scenarios.

	Portfolio Weights		
Constraining Variable	Scenario I: Rp > 0.043	Scenario II: σp < 0.250%	Scenario III: Sp > 0.063
S&P US Bonds	0%	88.4%	88.4%
S&P US REITs	100%	1.4%	1.4%
S&P Listed PE	0%	0%	0%
S&P Global 1200 equities	0%	10.2%	10.2%
Total (Check)	*100%*	*100%*	*100%*
Rp (Portfolio Expected Return)	0.043%	0.017%	0.017%
σp (Portfolio Risk)	2.297%	0.216%	0.216%
Max Sharpe Ratio (Rp/σp)	0.0187	0.0784	0.0784

Thereafter, we modified the base portfolio by either adding clean energy as a new asset class or by replacing one of the existing asset classes with clean energy to test the two defined hypotheses.

3.1.2.1. Addition of clean energy as a new asset class (Question/Hypothesis I)

In this section, we added the clean energy index to the base portfolio and performed the analysis again. The results were similar to those for the unconstrained scenario. Adding clean energy does not improve the portfolio's risk-return profile: for any particular scenario, there is no change in the maximum value of the Sharpe ratio in Table 5 vs Table 6. That is, we do not find evidence to support Hypothesis I.

Table 6. Portfolio Optimization for 10-year data with clean energy under different constrained scenarios.

	Portfolio Weights		
Constraining Variable	Scenario I: Rp > 0.043	Scenario II: Ơp < 0.250%	Scenario III: Sp > 0.063
S&P US Bonds	0%	88.4%	88.4%
S&P US REITs	100%	1.4%	1.4%
S&P Listed PE	0%	0.0%	0.0%
S&P Global 1200 equities	0%	10.2%	10.2%
S&P Clean energy	0%	0%	0%
Total (Check)	*100%*	*100%*	*100%*
Rp (Portfolio Expected Return)	0.043%	0.017%	0.017%
Ơp (Portfolio Risk)	2.297%%	0.216%	0.216%
Max Sharpe Ratio (Rp/Ơp)	0.0187	0.0784	0.0784

This is not surprising given that the constrained scenario is a subset of the unconstrained scenario and had there been any non-zero allocation level for clean energy which would have improved portfolio's expected performance, it would have already showed up in the results for the unconstrained scenario.

3.1.2.2. Replacing an existing asset class with clean energy (Question/Hypothesis II)

Similar to what we did for the unconstrained scenario, we replaced one asset class (at a time) to assess whether or not it erodes value of the portfolio. We performed the analyses over three constraints identified earlier in Section 3.1.2.

(i) Constraint 1 (minimum return): Portfolio's expected return should exceed or be equal to highest expected return of any individual asset class (Rp ≥ 0.043%).

(ii) Constraint 2 (maximum risk): Portfolio's expected risk should be less than or equal to the lowest expected risk of any individual asset class (Ơp ≤ 0.250%).

(iii) Constraint 3 (minimum Sharpe ratio): Portfolio's Sharpe ratio should be higher than or equal to the highest Sharpe ratio of any individual asset class (Portfolio Sharpe ratio or Sp ≥ 0.063).

As can be seen in Table 7, 8 and 9, at no instance does replacing an existing asset class increase the portfolio's Sharpe ratio. At the few instances, where the Sharpe ratio is equal to that of the base portfolio, the allocation towards clean energy for such instances is 0%. This means that had clean energy been assigned a value greater than 0%, the portfolio's Sharpe ratio would have declined; because, had the Sharpe ratio increased, then that would have showed up as an optimized result.

Therefore, from the results of the analyses, we can conclude that replacing an asset class with clean energy erodes the value of the portfolio. That is, we do not find evidence to support Hypothesis II.

Table 7. Portfolio optimization when individual asset classes are replaced under Scenario I.

Portfolio Weights					
Portfolio Return (Rp) ≥ 0.043%					
	Base Portfolio	Replaced asset class			
Constraining Variable	*(without clean energy)*	Bonds	REITs	PE	Equities
S&P US Bonds	0%	-	-	0%	0%
S&P US REITs	100%	100%	-	100%	100%
S&P Listed PE	0%	0%	-	-	-
S&P Global 1200 equity	0%	0%	-	0%	0%
S&P Clean energy	-	0%		0%	0%
Total (Check)	*100%*	*100%*	*No Solution*	*100%*	*100%*
Portfolio Return (Rp)	0.043%	0.043%	-	0.043%	0.043%
Portfolio Risk (σp)	2.297%	2.297%	-	2.297%	2.297%
Max Sharpe Ratio (Rp/σp)	0.0187	0.0187	-	0.0187	0.0187

Table 8. Portfolio optimization when clean energy replaces individual asset classes under Scenario II.

Portfolio Weights					
Portfolio Risk (σp) ≤ 0.250%					
	Base Portfolio	Replaced asset class			
Constraining Variable	*(without clean energy)*	Bonds	REITs	PE	Equities
S&P US Bonds	88.4%	-	88.0%	88.4%	92.7%
S&P US REITs	1.4%	-	-	1.4%	2.9%
S&P Listed PE	0%	-	0%	-	4.3%
S&P Global 1200 equity	10.2%	-	12.0%	10.2%	-
S&P Clean energy	-	-	0%	0%	0%
Total (Check)	*100%*	*No Solution*	*100%*	*100%*	*100%*
Portfolio Return (Rp)	0.017%	-	0.017%	0.017%	0.017%
Portfolio Risk (σp)	0.216%	-	0.215%	0.216%	0.225%
Max Sharpe Ratio (Rp/σp)	0.0784	-	0.0780	0.0784	0.0743

Table 9. Portfolio optimization when an individual asset class is replaced under Scenario III.

Portfolio Weights					
$Sp \geq 0.063$					
	Base Portfolio	Replaced asset class			
Constraining Variable	Base Portfolio *(without clean energy)*	Bonds	REITs	PE	Equities
S&P US Bonds	88.4%	-	88.0%	88.4%	92.7%
S&P US REITs	1.4%	-	0%	1.4%	2.9%
S&P Listed PE	0%	-	0%	-	4.3%
S&P Global 1200 equity	10.2%	-	12.0%	10.2%	-
S&P Clean energy	-	-	0%	0%	0%
Total (Check)	*100%*	*No Solution*	*100%*	*100%*	*100%*
Portfolio Return (Rp)	0.017%	-	0.017%	0.017%	0.017%
Portfolio Risk (Ơp)	0.216%	-	0.215%	0.216%	0.225%
Max Sharpe Ratio (Rp/Ơp)	0.0784	-	0.0780	0.0784	0.0743

3.2. 5-year and 3-year data

The exercises we performed for 10-year data were repeated for the 5-year and the 3-year data. While there were variations in the finer details, the broader trends remained the same:

a) Clean energy did not add value to the base portfolio since the Sharpe ratios did not improve (on adding clean energy as a separate asset class). Moreover, optimization resulted in a zero-percentage allocation towards clean energy. That is, we do not find evidence to support Hypothesis I.

b) On replacing any of the asset classes in the base portfolio with clean energy, the portfolio's Sharpe ratios declined. In cases where the Sharpe ratio was equal to that of the base portfolio, allocation towards clean energy was 0%. Thus, replacing any of the existing asset classes with clean energy erodes the value of the portfolio. That is, we do not find evidence to support Hypothesis II.

3.3. Discussion

Based on our analysis for 10-year, 5-year and 3-year data for constrained and unconstrained scenarios, we have arrived at the following conclusions:

Table 10. Conclusions of hypotheses.

Hypothesis	Result of Analysis	Conclusion
Hypothesis I: Treating clean energy as a separate asset class adds value to existing portfolios.	Clean energy was allocated zero percentage to the overall portfolio.	Hypothesis I is false; adding clean energy as a separate asset class does not add value to the base portfolio.
Hypothesis II: Treating clean energy as a separate asset class does not erode value of the existing portfolios.	On replacing any of the asset classes in the base portfolio with clean energy, the portfolio's risk-return metrics would go down.	Hypothesis II is false; treating clean energy as a separate asset class would erode value of existing portfolios.

Our analyses show that at this time, and with this method and data, there is not enough evidence that would support investors adding clean energy as a separate asset class in order to increase expected returns or lower risks for their overall portfolios. Though we do not rule out the possibility that clean energy investments may add value to a portfolio in specific situations, our simple analysis fails to show that clean energy, in general, would add value to a portfolio as an asset class. Given the conclusions, it is not surprising to see actual investments trailing the required investments by a huge margin. We note that out findings for listed clean energy investments are consistent with similar findings for listed infrastructure (Idzorek and Armstrong, 2009), green mutual funds (Roberedo et al, 2017), and clean energy exchange traded funds (Monaca et al, 2018).

4. Conclusions

As discussed in Section 3, the results of the analyses warrant a need for deeper investigation into why clean energy does not add value to a portfolio. Until the clean energy sector offers risk-reward profiles that are on par with other major sectors, it would not play a major role in strategic asset allocation and will continue to attract limited investment. Investors will continue to scout for opportunities at the tactical asset allocation level, which may only be present selectively and on a case-by-case basis; however, these alone will not be sufficient in attracting capital worth $2.3 trillion/year. One potential avenue of inquiry may be into using more nuanced datasets, e.g. either a listed equity index using only renewable energy generation companies or an unlisted equity index (e.g., from EDHEC, 2018). Another potential avenue may be into using more sophisticated analytical techniques, such as liability driven optimization (BlackRock, 2014). A third potential inquiry may be into exploring policy and regulatory support required to ensure that renewable energy investments provide value to investment portfolios (Deutsche Bank, 2012).

In this context, we note that financial portfolio performance measurements may not be directly used to make specific policy recommendations, because portfolio performance reflects historical trends and does not investigate the reasons behind these trends. For instance, if the returns were low, were they low because of high cost of capital, or because of high input prices such as the cost of land, or high corporate tax rate, or a combination of all of the above? A separate study may establish causes responsible for the trends, which can then be used to inform policy changes.

This study, however, does provide an economic justification for the ongoing investment trends in the clean energy sector, even if these trends are undesirous. It affirms that actual investments do not trail the required investments merely because of perceived low performance of the clean energy sector, but because actual performance of the sector is indeed lower than the requisite levels. That is, the findings of the study can be used as a basis for opining that the extant support to the sector, while significant, is still not enough and that there is a need to accelerate policy changes.

In short, this research confirms that a significant amount of work still needs to be done to make the clean energy sector more conducive for investment at scale. The governments, the development sector and the private sector will all be instrumental in devising a long-term and consistent policy framework (Deutsche Bank, 2011), facilitating more sector-specific information to the market, and developing catalytic interventions to mobilize private investments at scale.

Through the aforementioned steps, clean energy's risk-return metrics need to be improved, which will inadvertently result in higher flow of capital to the sector, and thus help in achieving the targeted investment levels to reach the 2C climate goals.

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Conflict of interest

The authors declare no conflict of interest in this paper.

References

Bianchi RJ, Bornholt G, Drew ME, et al. (2014) Long-term U.S. Infrastructure Returns and Portfolio Selection. *J Bank Finance* 42: 314–325.

Bird R, Liem H, Thorp S (2014) Infrastructure: Real Assets and Real Returns. *Eur Financ Manag* 20: 802–824.

BlackRock (2014) Alternatives and Liquidity: Incorporating Liquidity Constraints into Portfolio Construction. Available from: https://www.blackrock.com/institutions/en-zz/literature/publication/investment-insights-incorporating-liquidity-constraints.pdf.

Blake D, Lehman B, Timmerman A (2015) Asset Allocation Dynamics and Pension Fund Performance. *J Bus* 72: 429–461.

Blanc-Brude F, Whittaker T, Wilde S (2017) Searching for a Listed Infrastructure Asset Class using Mean Variance Sampling. *Financ Mark Portf Manage* 31: 137–179.

Cherewyk P (2018) Calculating Covariance for Stocks. Available from: https://www.investopedia.com/articles/financial-theory/11/calculating-covariance.asp.

Credit Suisse (2010) Can Infrastructure Investing Enhance Portfolio Efficiency? Available from: https://www.creditsuisse.com/pwp/am/downloads/marketing/infrastructure_ch_uk_lux_ita_scandinavia.pdf.

Cremers KJM (2013) The Performance of Direct Investments in Real Assets: Natural Resources, Infrastructure and Real Assets.

Damodaran A (2018) Estimating Risk Parameters.

Davidow A (2018) Why Global Diversification Matters. Available from: https://www.schwab.com/resource-center/insights/content/why-global-diversification-matters.

Deutsche Bank (2011) Get FIT Plus, De-Risking Clean Energy Business Models in a Developing Country Context. Available from: https://www.db.com/cr/en/docs/GET_FiT_Plus_Studie_der_Deutsche_Bank_Climate_Change_Advisors_(en).pdf.

Deutsche Bank (2012) Investment Markets and Strategic Asset Allocation: Broadening and Diversifying the Approach. Available from: https://www.db.com/cr/en/docs/Inv_in_CC_2012.pdf .

Deutsche Bank (2013) The Performance of Direct Investments in Real Assets: Natural Resources, Infrastructure, and Commercial Real Estate.

Dowell G, Hart S, Yeung B (2000) Do Corporate Environmental Standards Create or Destroy Market Value. *Manage Sci* 46: 1059–1074.

EDHEC (2018) Unlisted Infrastructure Asset-Pricing Methodology. Available from: http://edhec.infrastructure.institute/wp-content/uploads/documents/documentation/asset_pricing.pdf .

Filbeck G, Gorman RF (2004) The relationship between the environmental and financial performance of public utilities. *Environ Resour Econ* 29: 137–157.

Fulton MB, Kahn M, Sharples C (2012) Sustainable Investing: Establishing long-term value and performance. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2222740.

IEA (2016) World Energy Outlook. Available from: https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html.

Hart SL, Ahuja G (1996) Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance. *Bus strategy Environ* 5: 30–37.

Idzorek T, Armstrong C (2009) Infrastructure and Strategic Asset Allocation: Is Infrastructure an Asset Class? *Tech Rep Ibbotson Associates.*

Investopedia (2018) Mean-Variance Analysis. Available from: https://www.investopedia.com/terms/m/meanvariance-analysis.asp.

IVG research (2012) The importance of infrastructure asset class in multi-asset portfolio. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1992520.

King RG, Plosser CI, Rebelo ST (2002) Production, Growth and Business Cycles: Technical Appendix. *Comput Econ* 20: 87–116.

Lioudis N (2017) Sharpe Ratio. Available from: https://www.investopedia.com/articles/07/sharpe_ratio.asp.

Little K (2017) Common Asset Classes in Portfolio. Available from: https://www.thebalance.com/use-all-four-asset-classes-to-build-your-portfolio-3141071.

Margolis JD, Hillary EA, Walsh JR (2009) Does It Pay To Be Good? A Meta-Analysis and Redirection of Research on the Relationship between Corporate Social and Financial Performance. *MIT Sloan Manage Rev* 50:61–68.

Mercer (2009) Shedding Light on Responsible Investment: Approaches, Returns and Impacts. Mercer report.

Markowitz HM (1952) Portfolio Selection. *J Financ* 7: 77–91.

Muller S (2005) Constrained Portfolio Optimization. University of St. Gallen.

Merton R (1972) An Analytical Derivation of the Efficient Frontier. *J Financ Q Anal* 7: 1851–1872.

Monaca SL, Assereto M, Byrne J (2018) Clean Energy Investing in Public Capital Markets: Portfolio Benefits of YieldCos. *Energy Policy* 121: 383–393.

Newell G, Peng HW, De Francesco A (2011) The Performance of Unlisted Infrastructure in Investment Portfolios. *J Prop Res* 1: 59–74.

Obaidullah J (2018) Portfolio Standard Deviation.

Orlitzky M, Schmidt FL, Rynes SL (2003) Corporate Social and Financial Performance: A Meta-Analysis. *Organ Stud* 24: 403–441.

Reicher D, Brown J, Fedor D, et al. (2017) Derisking Decarbonization: Making Green Energy Investments Blue Chip.

Roberedo J, Quintela M, Otero L (2017) Do Investors Pay a Premium for Going Green? Evidence from Alternative Mutual Funds. *Renew Sustain Energy Rev* 73: 512–520.

Rosenthal JL (2006) Portfolio Theory.

Rothballer C, Kaserer C (2012) The Risk Profile of Infrastructure Investments: Challenging Conventional Wisdom. *J Struct Finance* 18: 95–109.

Russo MV, Fouts PA (1997) A Resource-Based Perspective on Corporate Environmental Performance and Profitability Auth. *Academy Manage J* 40: 534–559.

Sanzilo T, Chung Y, Buckley T (2017) Making the case for Norwegian Sovereign Wealth Fund Investment in Renewable Energy Infrastructure; Institute for Energy Economics and Financial Analysis.

S&P Indices (2018) Available from: https://us.spindices.com/indices/equity/sp-global-clean-energy-index.

Smirnov Y (2018) Standard Deviation of Portfolio.

Telle K (2006) It Pays to be Green A Premature Conclusion. *Environ Resour Econ* 35: 195–220.

Wikipedia (2018) Variance-Covariance Matrix. Available from: https://en.wikipedia.org/wiki/Covariance_matrix.

Wright C (2012a) How to build a variance-covariance matrix? Available from: https://www.youtube.com/watch?v=ZfJW3ol2FbA.

Wright C (2012b) How to perform mean variance optimization on Excel? Available from: https://www.youtube.com/watch?v=FZyAXP4syD8.

Ziegler A, Seijas Nogareda J (2009) Environmental management systems and technological environmental innovations: Exploring the causal relationship. *Res Policy* 38: 885–893.