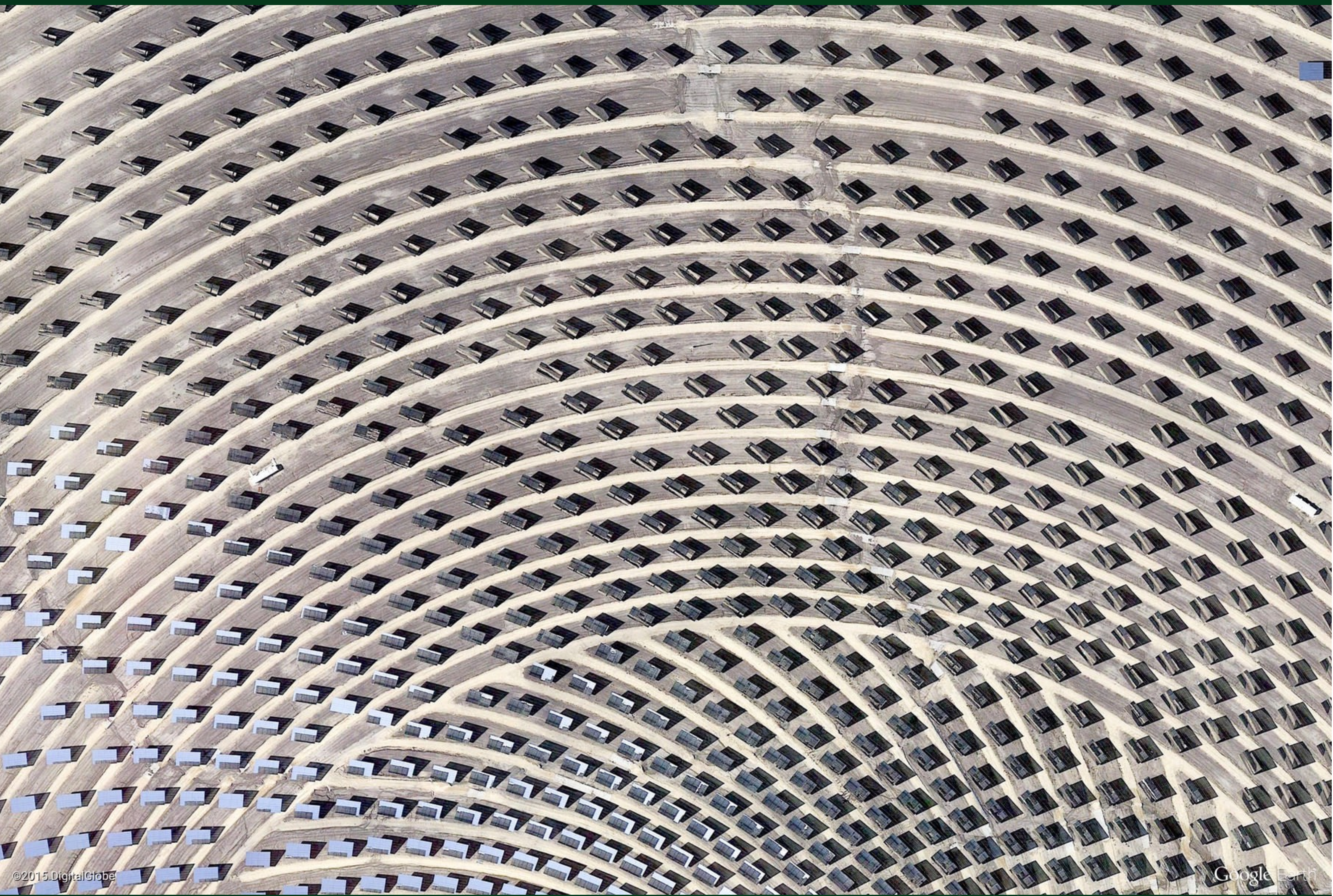
The Pricing of Green Infrastructure

The realised and expected financial performance of green power infrastructure investment, 2010-2021



EDHEC*infra*
Research publication

September 2022

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Executive Summary

In 2011, green power projects had expected returns of 8% and brown power projects 9%. Their 10-year annualised total returns in 2021 were 16% and 17% respectively. These two figures may seem related but correspond in fact to very different economic fundamentals.

In modern asset pricing theory, the long-term equilibrium of asset prices is such that expected returns i.e., discount rates must reflect the risks to which investors are exposed. However, over shorter periods of time, persistent shifts in investor preferences or 'taste' for certain investments can also have an impact on asset prices as the demand for these assets changes and supply responds. Investment in green power infrastructure is a case in point. A decade ago, few large institutional investors had exposure to wind and solar power projects. Today, such investments represent between a quarter and a third of a growing allocation to infrastructure investment (see Blanc-Brude et al., 2022).

In this paper, we examine the impact on realised performance of this permanent shift in investor preferences for low carbon energy investments, and how it relates to the expected returns of green power investments. We show that while green infrastructure has outperformed the 'Core' infrastructure market over the past decade, this is largely the result of excess demand for such assets that has pushed asset prices up and discount rates down. We find that controlling for a number of risk factors that are present in the returns of unlisted infrastructure equity investment, there is no persistent 'green' risk factor, but instead a 'green price premium' that investors have been willing to pay to increase their holdings of such assets.

We construct a 'green minus brown' or GMB power infrastructure portfolio that would, in theory, replicate a green risk factor, using a portfolio of pure green power investments (wind and solar) and one of pure brown power investments (coal and gas). Controlling for the effect of well-documented risk factors like size, leverage and profits, the GMB portfolio produces a statistically significant negative alpha.

Prima facie, this result could be interpreted as the presence of a 'green' risk factor in the returns of green and brown power infrastructure investments. However, we show that the evolution of cost of capital spread between the two 'legs' of the GMB portfolio explains away its negative alpha. In other words, taking yield compression into account, standard pricing factors suffice to explain the realised performance of the GMB portfolio.

We show this impact of excess demand for green power investments on yield compression by building a measure of the liquidity of the market for green power investment. When too few green infastructure investments are available in the market, asset prices increase and yields compress. Controlling for this effect, any outperformance of the green power sector over the considered period disappears.

We find that this phenomenon peaks in 2019 and that the expected returns of green power investments are now much lower than they used to be i.e., their pice is higher. It follows that realised returns should not be used directly as a proxy of the future performance of green power investments.

1. Introduction

It is often argued that more sustainable investments should coincide with better financial performance. This opens two distinct questions:

- Firstly, is there any empirical evidence of superior performance by more sustainable or greener investments? And if so, what might explain such outperformance, and can it be expected to persist in the future?
- Alternatively, is it the result of an identifiable transition in investor preferences resulting in a positive shift in asset prices (higher realised returns) but not in higher *expected* returns?

In this paper, we show that there is indeed empirical evidence of historical outperformance of *green infrastructure* investments (defined narrowly as wind and solar power projects). We then consider whether this finding implies continued future outperformance. In line with the literature, we argue that more sustainable infrastructure investments should *in fine* have lower expected returns than less sustainable ones, but that the recent shift in investor preferences in favour of greener power investments temporarily created excess demand, explaining realised performance during the past decade.

The existence of a systematic difference in pricing and expected returns between sustainable and less sustainable investments is examined in recent academic research ((see Pastor et al., 2022; Alessi et al., 2021)). Pastor *et al.* summarise the reason why greener investments should have low expected returns: either investors bid up asset prices because they have increasing preferences for them, or the customers of greener businesses shift their demand towards their services, increasing their revenues and profits, and consequently their market value. As asset prices rise in response to greater demand, their cost of capital falls. In other words, the premise that greener companies and services – and the positive externalities they create – are increasingly valuable to investors and desirable to consumers (and the reverse for less green companies) implies that the market price of their equity must be higher, their cost of capital lower and their expected return (which, in equilibrium, must equal their cost of capital) also lower. As long as we accept the hypothesis of weakly efficient financial markets, in equilibrium risk must be adequately priced, which leaves little hope for the continued high performance of green infrastructure investments in the near-to-long term.

Of course, in this context, it is still possible for greener investment to outperform during a period of persistent changes in investor preferences; for example, excess demand can drive up asset prices because investors expect preferences for green assets to have durably shifted from their previous level. As market prices increase and capital gains accrue to investors, these investments outperform but also exhibit increasingly lower expected returns.

As (Pastor et al., 2021) and others point out, the inverse relationship between price and expected return or yield is at its simplest in the case of bonds. For a buy-and-hold investor, the yield of a bond is the best estimate of its expected return, as bond prices change, its yields and expected returns change inversely. This is because bonds have no exposure to the upside i.e., the growth of the borrowers' business. The same mechanism applies to the price and yield one the most clear-cut types of sustainable investments: green power infrastructure.

Green infrastructure can take several forms, but at its greenest, it can be narrowly defined as wind and solar power projects: new investments producing electricity (largely) without emitting greenhouse gases and potentially displacing existing power sources that do. In other words, with constant energy needs, wind and solar power projects are carbon-negative investments. This category of investments thus provides a convincing case of what the *greenest* types of green infrastructure investments might look like.

The way such projects are created and financed is what makes them resemble a bond. Solar and wind farms are typically incorporated as a standalone special-purpose company with a finite life based on the economic life of the physical asset and on its business model, typically a revenue mechanism [1] or a long-term power purchase agreement (PPA). Such projects raise asset-backed finance once, sink capital into a finite physical asset, and its investors are repaid over a period of 25 to 30 years. Like bonds, such a company has very limited upside or growth options. Wind farms can be repowered and PPAs extended, but infrastructure assets are capacity-constrained by design. Infrastructure companies thus have a maximum potential revenue defined mostly by *ex-ante* choices of size and technology. Hence, like many other project-based infrastructure investments, wind and solar project equity investments are akin to a bond with risky coupons.

It follows that if increasing demand for green infrastructure leads to higher returns through capital gains, it must be because their yield or costs of capital is falling. it also follows that once excess demand has been absorbed by the market, the long-term performance of greener infrastructure should be lower than that of less green infrastructure investments.

1 - e.g., Renewable Obligation Certificates, Feed-In Tariffs or Contracts for Difference

In what follows we consider the question of what drives the past and future financial performance of green infrastructure in several steps.

We first review the historical performance of investments in unlisted wind and solar project equity using the infraGreen index.[2] We show that green infrastructure investments have indeed outperformed the market, including Core infrastructure which is a natural benchmark for such projects. Until 2019, they also outperformed Core+ infrastructure, a riskier subset of unlisted infrastructure investments. In effect, over the past 10 years, green infrastructure has exhibited a very attractive risk-adjusted return profile, with higher annualised returns than Core infrastructure and lower volatility than Core+ infrastructure.

We then follow the literature and examine the difference of performance between two portfolios created using asset-level data available in the EDHEC*infra* database: a *green* power portfolio of unlisted equity investments in wind and solar projects *only*, and a *brown* power portfolio of unlisted equity investments in coal and gas power projects *only*. As argued above, we consider all the investments in the first portfolio to be equally (and highly) green. Likewise, coal and gas power projects are unequivocally brown:[3] coal and gas power projects are net contributors to greenhouse gas emissions. Conventional power generation emitted 13.5GtCO2-eq in 2020, i.e., it is the first contributor to total energy-related emissions (31GtCO2-eq, IEA (2021)) before the transportation and industry sectors. Even though the greenhouse gas emissions of coal and gas power projects vary and can, to some extent, be reduced or captured, even with constant energy demand, these investments are *always* carbon positive. In other words, our green power portfolio is *always* greener than our brown power portfolio.

2 - The infraGreen index is available on the infraMetrics platform of EDHEC*infra*.

3 - Irrespective of the debate on the inclusion of natural gas generation in the EU taxonomy (See Blanc-Brude *et al.* 2021)

Over a period extending from 2011 to 2021, the brown power portfolio outperformed green power by a cumulative 138bp. However, during that period, green power outperformed or matched the performance of brown power between 2012 and 2015 and also between 2018 and 2020. We show that these are also the two periods during which the cost of capital spread between green and brown power widened significantly as the market value of green power assets increased.

Next, we examine the differential performance of green and brown power investments through a "green minus brown" (GMB) portfolio of their returns over the past decade. Controlling for the effect of well-documented risk factors like size, leverage and profits, this portfolio produces a statistically significant negative "alpha". The realised green or brown power excess returns are also better explained by adding a GMB 'effect' to the usual set of risk factors. *Prima facie*, this result could be interpreted as the presence of a 'green' risk factor in the returns of green and brown power infrastructure investments.

To determine the potential persistence of this effect, we examine the expected returns of green and brown power using data from infraMetrics and show that there is a significant and increasing spread between the weighted average cost of capital of the two portfolios. The weighted average cost of capital (or WACC) spread or *green price premium* between the green and brown power portfolios is consistently negative and growing: in 2021, it has widened to reach almost -350bp from about -100bp a decade earlier.

High realised performance has been accompanied by a significant decrease in the cost of capital of green power infrastructure. In effect, all infrastructure investments have become more popular amongst investors in the past decade and have seen a reduction in their cost of capital, including brown power. However, the green power sector has seen a much larger decrease. Between December 2011 and December 2021, the infrastructure market saw a global reduction in WACC of 177bp (from 7.23% to 5.45%), while green power saw a greater reduction of 263bp, but the WACC of brown power is only 11bp lower in 2021 than it was in 2011.

We show that the evolution of cost of capital spread of the two legs of the GMB portfolio explains away its negative alpha. In other words, taking yield compression into account, standard pricing factors suffice to explain the realised performance of the GMB portfolio.

We argue that the yield compression observed since 2011 is at least in part due to excess demand in the market for green power infrastructure i.e., demand that cannot be met immediately by a supply of green power investments. To show this effect, we construct a measure of excess demand for green power investments using the share of secondary transactions in all investments made by infrastructure investors in green energy. We argue that periods during which secondary transactions represent a smaller fraction of the overall market transaction volume are periods of lower liquidity – during which excess demand for green power assets is likely to have been higher. We show that this measure of the green power market liquidity is strongly related to the performance and WACC spread of the GMB portfolio, as well as the realised performance of the green power portfolio. In other words, when the market for renewable power projects is less liquid and excess demand is more likely to build up, we tend to see an increase in the performance of the GMB portfolio and in the WACC spread between green and brown assets.

We conclude that, while green power assets have experienced a period of strong performance (realised returns), they are likely to deliver lower returns going forward since this performance was largely driven by the compression of their cost of capital, itself largely related to the build-up of excess demand in the market for green assets.

Moreover, while the green price premium has increased in line with excess demand, the supply of green power investments has also increased considerably and the GMB WACC spread has been flat since 2019. As green infrastructure plays an increasingly important and ubiquitous role in investors' portfolios, a consensus on the price and expected returns of green power is increasingly likely and new shifts in demand for such assets less so. In effect, green power may be one the few asset classes in which green pricing has already peaked (around mid 2019).

These results are important in understanding the role that renewables and conventional energy are likely to play in investors' portfolios going forward, since increasing allocations to green energy should not be based on returns assumptions derived from historical returns. Indeed, as the supply of renewable investments has increased and, in some markets, become one of the dominant sources of energy, investor preferences for such assets should stabilise and excess demand disappear. A recent peer-group survey of asset allocations within the infrastructure asset class found that renewable energy already represents one quarter to one third of most investors' infrastructure portfolios (Blanc-Brude et al., 2022). While investment in green infrastructure is likely to keep increasing on aggregate, its weight in infrastructure portfolios is unlikely to keep increasing monotonically.

Durably lower expected returns and cost of capital for green power is of course a good thing, since it reduces the overall cost of the energy transition. However, investors should not expect to receive high returns while contributing to the energy transition (have a positive impact) as long as they are only exposed to a pure, unleveraged basket of green power investments.

This paper builds on the growing literature on green vs. brown investments (see Pastor et al., 2022, for a summary) but provides a new perspective by examining the behaviour of asset prices in the market for unlisted infrastructure equity, complementing available evidence from listed assets. The literature has investigated the existence of a green factor using long-short portfolios of assets weighted by their greenness (Pastor et al., 2021). Focusing on infrastructure assets enables a cleaner identification of green exposure compared to listed assets: while the shares of listed company correspond to exposures to a range of climate-relevant assets and projects in different locations, the analysis of well-identified infrastructure energy projects provides a direct measure of exposure to greenness. Hence, the existence of a green premium may be measured more reliably in infrastructure markets than in public markets.

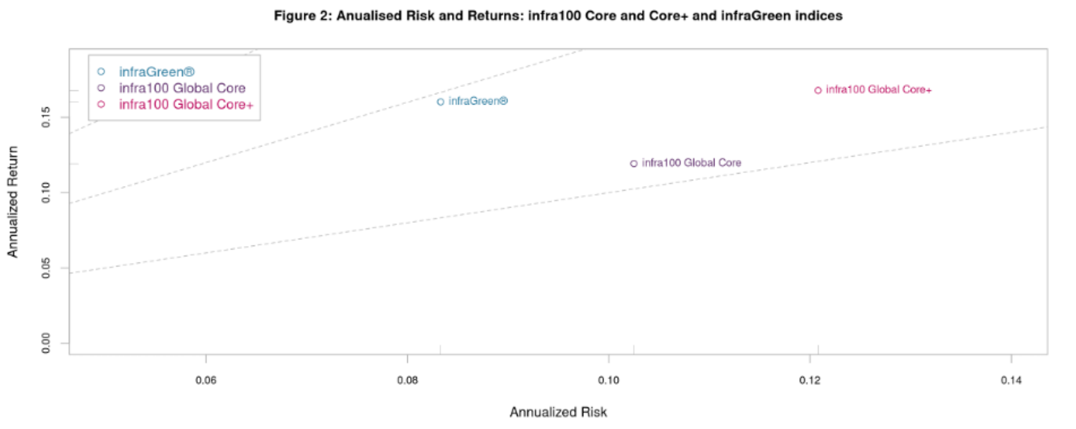
The rest of the paper is organised thus: Section 1 details the historical performance of the infraGreen index in comparison with the Core and Core+ segments of the unlisted infrastructure universe. Section 2 provides a comparative analysis of a green and a brown power infrastructure portfolio. Section 3 investigates the presence of a systematic *green effect* in the valuation of green power infrastructure investments. Sector 4 considers the role of excess demand in explaining the historical performance of green power investments and uses a proxy of this demand to adjust the historical performance of green investments. Section 5 compares the evolution of the cost of capital of green and brown power infrastructure and explores how the current green price premium implies that future investors in greener infrastructure should expect lower returns.

Table 1: Descriptive Statistics, monthly local currency returns (2010-2021)

	infraGreen®	infra100 Global Core	infra100 Global Core+
Mean	0.013	0.010	0.014
Median	0.011	0.011	0.015
StdDev	0.024	0.030	0.035
Semi-Variance	0.023	0.031	0.038
Sharpe ratio	0.496	0.306	0.367
Kurosis	0.250	0.057	0.973
Skewness	0.080	-0.324	-0.552

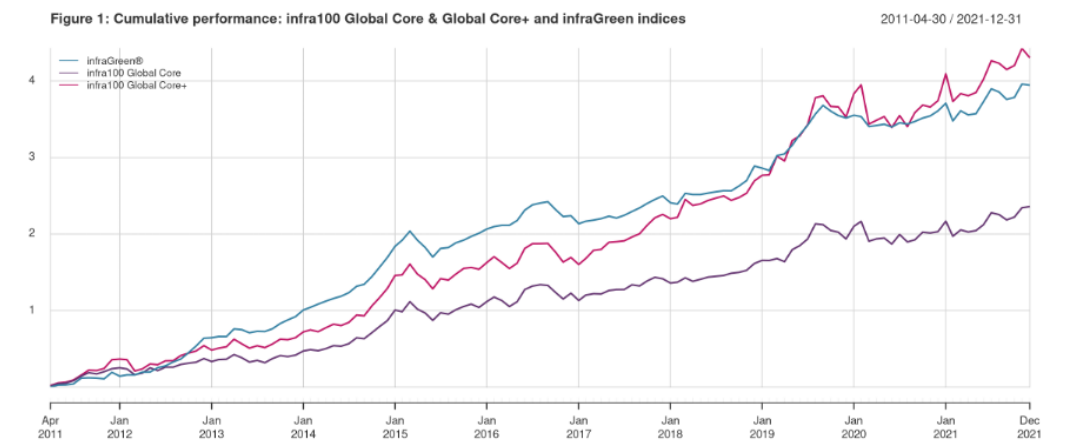
Source: infraMetrics®

*Figure 1: infraGreen, infra100 Global Core and infra100 Global Core+ indices**



*equal weights, local currency total returns

*Figure 2: infraGreen, infra100 Global Core and infra100 Global Core+ indices**



*Equal weights, local currency total returns

2. The Performance of Green Power Infrastructure

The infraGreen index tracks the market performance of 100 unlisted wind and solar power projects worldwide. Because of the contracted nature of their business model and priority access to the electric grid, wind and solar power projects are considered relatively low risk compared to other types of infrastructure investments.

Thus, an intuitive benchmark for the infraGreen index is so-called *Core* infrastructure. In infraMetrics, *Core* is defined as the lower two quartiles of infrastructure investments ranked by five-year trailing expected returns.[1]

One third of the infraMetrics® Core infrastructure market segment which includes more than 300 firms, is in the renewable power sector. The infra100 Global Core index, which tracks the 100 largest investments in the core segment of the market, includes 17% of renewable energy constituents.

We also compare the infraGreen performance with the infra100 Global Core+ index, corresponding to the third quartile of trailing expected returns, even though this index includes only 5% of renewable power investments.

Table 1 shows descriptive statistics of realised total monthly returns for the three market indices. infraGreen has a better realised risk/reward profile but also positive return skewness, unlike the Core and Core+ indices. Likewise, the semi-variance (downside volatility) of the infraGreen index is also lower than its volatility and its monthly Sharpe ratio is high, an indication that the sector went through a bull market.

Over the past decade, investments in renewable power have performed better than their natural benchmark (Core infrastructure) and approached the performance of Core+ infrastructure. As shown in Figure 1, the infraGreen index has performed better than Global Core and even outperformed the Global Core+ segment until 2019. Figure 2 further illustrates how the infraGreen index also delivered a much better risk-adjusted performance than the Core or Core+ segments of the private infrastructure market.

Next, we examine the difference between two portfolios of unlisted infrastructure equity investments build to capture each end of the green and brown spectrum.

1 - These indices are defined in terms of risk appetite: the infra100 Global Core tracks the 100 largest investments in the first two quartiles of the distribution of five-year-average expected returns. Similarly, the infra100 Core+ index tracks the 100 largest investments in unlisted infrastructure that fall into the third quartile of the distribution of five-year-average expected returns.

Table 2: Local currency monthly total returns, infraGreen and brown power portfolios, 2011-2021

	2011-2021		2011-2015		2016-2021	
	infraGreen	Brown Power Portfolio	infraGreen	Brown Power Portfolio	infraGreen	Brown Power Portfolio
Mean	0.013	0.014	0.020	0.016	0.007	0.009
Median	0.011	0.014	0.018	0.016	0.006	0.009
StdDev	0.024	0.024	0.027	0.025	0.019	0.022
Semi-Variance	0.023	0.026	0.027	0.026	0.019	0.023
Sharpe ratio	0.496	0.526	0.697	0.612	0.322	0.380
Kurtosis	0.250	0.592	-0.087	0.564	0.283	0.520
Skewness	0.080	-0.391	-0.198	-0.398	-0.140	-0.539

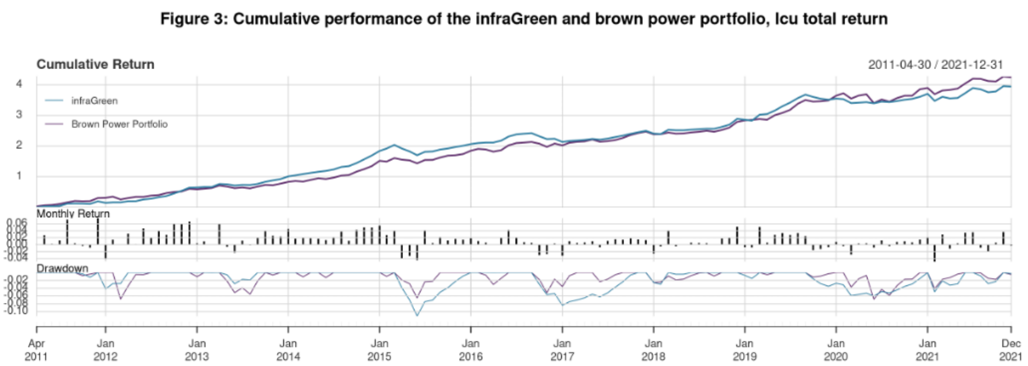
Source: infraMetrics®, calculations EDHEC*infra*

Table 3: Local currency monthly capital and income returns, infraGreen and brown power portfolios, 2011-2021

	Capital Retuns		Income Returns	
	Green capital returns	Brown capital returns	Green income returns	Brown income returns
Mean	0.006	0.003	0.008	0.011
Median	0.007	0.008	0.000	0.000
StdDev	0.031	0.032	0.027	0.028
Semi-Variance	0.033	0.041	0.008	0.010
Sharpe ratio	0.177	0.067	0.269	0.363
Kurtosis	-0.093	1.998	14.605	8.167
Skewness	-0.287	-1.210	3.777	2.991

Source: infraMetrics®, calculations EDHEC*infra*

Figure 3: infraGreen and brown power cumulative performance



*Equal weights, local currency total returns

3. Green vs Brown

While we cannot rank infrastructure investments using precise measures of greenness given the current state of the data, we can infer from the relative performance of the conventional power (brown) and of the renewable power (green) segments of the unlisted infrastructure market what 'high greenness' vs 'low greenness' look like.

As argued above, we assume that all wind and solar power projects are equally green and that all coal and gas power projects are equally brown, which is a simplification and does not permit using shades of green or brown to rank investments as the literature suggests. Still, we can argue that all renewable power investments are always greener than all conventional power investments. That is because at one point in time, given energy demand and the priority dispatch rules from which renewables benefit, renewables power investments are carbon negative[1] (i.e. they displace carbon emissions that would otherwise take place through conventional power generation). Conversely, as a portfolio, conventional power is always strictly carbon positive.

We compare two portfolios using equally weighted monthly returns from the infraMetrics database spanning a decade 2011 to 2021:[2]

- A portfolio of *green* power investments in solar farms and winds farms in a range of countries, primarily Europe: the infraGreen index includes 100 green investments in wind and solar projects worldwide, representing USD15bn of market value in December 2021;
- A portfolio of *brown* power investments in conventional coal- and gas-fired power plants: 76 investments in fossil-fuel power projects representing USD26bn of market value.

Table 2 reports the descriptive statistics of the monthly returns of the two portfolios. Over the past decade, realised returns have been higher in the brown investment segment but before 2016 the reverse was true, while since 2016 the average monthly returns in the green segment have been lower than those of the brown segment.

Table 3 shows that a significant part of the performance of green infrastructure can be explained by capital gains, which have been twice are high as those of the brown power segment over the period. Conversely, brown power has produced higher cash returns.

Figure 3 shows the cumulative performance of the green and brown power portfolios. After a period during which green power infrastructure performed better (for the reasons highlighted above), since early 2019 the cumulative performance of the green power portfolio perform has fallen below that of the brown power.

1 - This is not necessarily always true depending on power price dynamics, demand growth, curtailment and other factors that impact power generation.

2 - The panel is unbalanced: the number of green investments tends to increase over time and that of brown investments tends to decrease.

4. Green *minus* Brown

In this section, we examine the drivers of the differences between the green and brown power portfolios which, in line with previous papers, is labelled GMB or the 'green minus brown' portfolio. We leverage the EDHEC*infra* asset pricing model of unlisted infrastructure equity to identify equity-like risk factors and regress the excess returns of the green and brown portfolios against the returns of each factor.

As usual, expected returns for portfolio i at time t are written:

$$r_{i,t} = \sum_{k=1}^{K} \beta_{i,k} \times \lambda_k$$

with K risk factors, where $\beta_{i,k}$ is the exposure of the portfolio to factor k and λ_k is the factor risk premium or factor return.

Risk factor returns

The EDHEC*infra* approach to asset pricing for unlisted infrastructure equity focuses on the role of several key factors that are documented determinants of the market discount factor: Size (total assets), Profits (Return on Assets), Leverage (Senior Debt over Total Assets) and Investment (Capex over Total Assets).[1]

To represent these factors, we build the following factor-mimicking portfolios using 20 years of monthly returns for 650 investments in the infraMetrics database:

- Size: the returns of investments in the top size quintile minus those of relatively smaller assets (bottom quintile)
- Leverage: the returns of highly leveraged assets (top quintile, excluding distressed assets with leverage over 100%) minus those of the least leveraged infrastructure investments
- Profits: the returns of the most profitable assets minus those of least profitable ones
- Investment: returns for the top quintile by capex minus those of the least capex-intensive investments

1 - The EDHEC*infra* methodology also includes a geographic parameter represented by the term spread on sovereign debt and several sector control variables.

Table 4 provides some descriptive statistics of factor returns. We see that the size factor, which denotes the return of a portfolio long large infrastructure assets and short small infrastructure assets, changes sign during the period: it is negative before 2015 (as is the case for public stocks – see Fama & French) but turns positive after 2015 as investors become increasingly interested in infrastructure and the demand for larger ("trophy") assets increases.

Leverage has a positive sign (indicating higher equity risk *ceteris paribus*) but its magnitude also decreases over time, as the market is willing to accept lower returns for similar levels of leverage. Likewise, the investment factor also shows a positive return, due to the higher equity risk created by construction periods and new capital expenditure programs. This factor return has increased over time, indicating that the market has been pricing capex risk more highly. Finally, the profit factor has delivered a negative return since more profitable infrastructure project have both survived their greenfield phase (during which profits are negative) and, given their limited re-investment opportunities in the asset, are more likely to pay dividends. However, we see that the return of the profit factor has considerably decreased over time, as investors become increasingly willing to invest in early life assets.

In line with previous research, we also build a Green *minus* Brown or GMB portfolio: the monthly return difference between the green and the brown power portfolios defined above. Figure 4 shows the rolling 12-month returns of the green, brown and GMB portfolios. As described above, the outperformance of green power compared to brown power is mostly limited to the 2012-2015 period, during which the GMB portfolio exhibits positive returns, and the 2017-2019 period during which the performance of green power increases to almost match that of brown power and the GMB portfolio has returns close to zero. The rest of the time, the GMB portfolio delivers negative returns, indicating that brown power exhibits higher realised excess returns i.e., green power has become durably expensive.

Table 4 also describes the GMB portfolio (last column): the sign of GMB portfolio returns is negative for the full period but in fact changes before and after 2015 from positive but close to zero to strongly negative by an order of magnitude.

Risk factor exposures

Before considering the impact of factor returns on green and brown power investments, we consider the exposure of the green and brown portfolios to each risk factor over time. Table 5 shows the descriptive statistics for the characteristics of the investments found in the green and brown power portfolios, and compares them with the broader market for the entire period, and for two subperiods, before and after 2015.

Green infrastructure projects are smaller, while brown projects are comparable in size to the broad market average. Indeed, wind and solar power projects tend to require less upfront capital due to smaller design capacities than conventional power plants. Both portfolios have a constant average size over time.

Green investments are also more leveraged than the market average, while brown ones are less leveraged. Green power investments tend to be project financed which allows investors to optimise the use of long-term debt financing. Average leverage tends to decrease slightly during the period during the period, especially for ageing brown power investments that are repaying their debt, while green power investments are younger and raised their debt more recently.

Investment (capex as a share of total assets) is highest in green power, also reflecting the relatively recent creation of these assets when compared with conventional power stations which have often be built long before. Before 2015, the exposure of the green index to the investment risk factor is even higher, as many of these assets are still in the earlier part of the investment lifecycle at the time. After 2016, the average exposure of the green index to the investment factor is markedly lower, but it is even lower in the brown power segment.

Finally, profits in green power investments are higher than both the brown investments and the market average. Green profits also tend to increase over time while they tend to decrease for brown power investments.

Thus, part of the performance differential between green power and brown investments springs from differences of exposures to certain risk factors during the period. Green power is smaller in size, which after 2015 should increase expected returns; it is more leveraged, which should also increase expected returns; it is still more heavily investing in the assets, which should also increase expected returns; but it is already more profitable than brown power infrastructure, which should reduce expected returns.

While, these exposures have changed over time, as green power investments have matured, and brown ones have aged, the relative differences between green and brown portfolios have not changed markedly expected for profitability

Figure 4: Green, Brown anf GMB returns, 12-month rolling, local currency

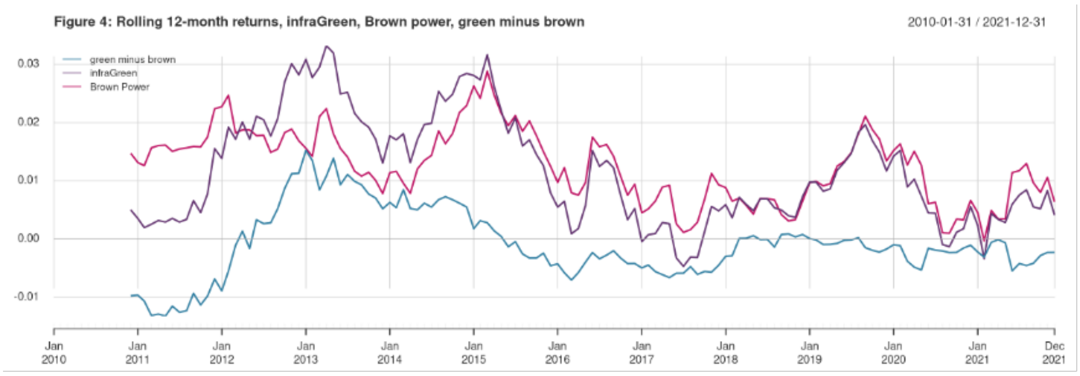


Table 4: Monthly factor returns descriptive statistics, 2011-2021, LCU

	Size	Leverage	Profit	Investment	Green
2011-2021					
Mean	-0.0020	0.0017	-0.0013	0.0020	-0.0007
Median	0.0005	0.0014	-0.0023	0.0026	-0.0013
StdDev	0.0244	0.0145	0.0173	0.0160	0.0154
Sharpe ratio	-0.0821	0.1208	-0.0781	0.1240	-0.0456
Semi-Variance	0.0263	0.0147	0.0148	0.0157	0.0147
Kurtosis	0.8088	2.4233	2.7949	8.4414	1.9351
Skewness	-0.4355	-0.3504	0.9535	0.8834	0.2181
2011-2015					
Mean1	-0.0045	0.0022	-0.0020	0.0018	0.0002
Median1	0.0002	0.0019	-0.0022	0.0030	0.0004
StdDev1	0.0226	0.0149	0.0168	0.0136	0.0171
Sharpe ratio1	-0.2004	0.1443	-0.1172	0.1344	0.0099
Semi-Variance1	0.0249	0.0154	0.0156	0.0150	0.0175
Kurtosis1	1.1858	2.2083	1.1754	1.3264	0.6819
Skewness1	-0.6434	-0.5648	0.4563	-0.5251	-0.1756
2016-2021					
Mean2	0.0026	0.0010	-0.0002	0.0023	-0.0021
Median2	0.0020	0.0008	-0.0025	0.0012	-0.0031
StdDev2	0.0269	0.0136	0.0182	0.0198	0.0121
Sharpe ratio2	0.0972	0.0733	-0.0122	0.1149	-0.1780
Semi-Variance2	0.0274	0.0135	0.0137	0.0166	0.0096
Kurtosis2	0.2091	2.8892	4.4068	8.9690	8.0949
Skewness2	-0.3730	0.1436	1.6193	1.6081	1.6774

Source: infraMetrics®, calculations EDHEC*infra*

Table 5: Average risk characteristics of infraGreen, brown power and the infra300 index, 2011-2021

	LogSize	Leverage	Profits	Investment
2011-2021				
Green Portfolio	18.317	0.814	0.142	0.101
Brown Portfolio	19.888	0.713	0.123	0.054
Market Index	19.805	0.769	0.110	0.084
2011-2015				
Green Portfolio1	18.320	0.821	0.132	0.147
Brown Portfolio1	19.977	0.740	0.127	0.067
Market Index1	19.751	0.773	0.110	0.102
2016-2021				
Green Portfolio2	18.315	0.808	0.151	0.064
Brown Portfolio2	19.728	0.666	0.114	0.030
Market Index2	19.907	0.763	0.109	0.049

Source: infraMetrics®, calculations EDHEC*infra*

which had increased in green assets and decreased slightly for the brown power portfolio.

Risk factor betas

To examine the performance drivers of the GMB portfolio, we regress its excess returns against the factor returns identified above (Table 6). The intercept only model (Model 1) fails to identify a clear effect, especially before 2015 i.e., the average level of the GMB effect is not significantly different from zero. This is not surprising as we know that the GMB portfolio's returns switch sign several times during this period. Model 2 incorporates the effect of the 4 factors and Model 3 adds a broad market factor (the infra300 index).

We see that the variance of the GMB is partly explained by movements in other factor returns with a high degree of significance, especially until 2015. During that period, about 55% of the GMB return variance is explained by the variance of other factors. Controlling for these effects, GMB retains a significant and negative intercept. From 2016, there is no significant effect of the size, leverage or other factors and the model fit as measured by the Adjusted r2 is very low (10 to 20 times lower than for the pre-2015 period). However, the model still exhibits a significant non-zero (negative) intercept of the same order of magnitude than before 2016.

Hence, while GMB returns are partly driven by market factors, they cannot be fully explained in terms of the traditional factors that tend to drive the equity risk premium in unlisted infrastructure equity markets.

Next, we also regress each leg of the GMB portfolio (green or brown power) against the usual risk factors and consider whether adding the GMB effect improves the explanatory power of the model i.e., to what extent does a GMB 'effect' help explain the returns of the green or the brown power portfolios when taking other factors into accounts.

Tables 7 and 8 show the weighted-least square regression results for the 2011-2021 period and the two sub-periods, as well as without (Panel A) and with (Panel B) the GMB portfolio used as an explanatory variable.

We find that GMB unsurprisingly loads positively in the green power portfolio and negatively on the brown power portfolios and that the adding it to the model significantly increases the goodness of fit of the model as measured by the adjusted r2 in both cases. In the case of green power, the GMB loading tends to decrease over time while it tends to increase over time, while the reverse is true for the brown power portfolio.

So far, we have documented the existence of systematic differences between the realised returns of well-identified green and brown power infrastructure investments. We also found that these differences at not constant over time but correspond to specific moments i.e. the periods of 2012-2015 and 2017-2019.

Next, we examine the evolution of the cost of capital of these two portfolios, that is, their *expected* returns, and how their evolution can explain the relative performance of green and brown infrastructure over time.

A Green Price Premium

Using asset-level data from infraMetrics, we compare the average WACC of each segment. We focus on the WACC rather than the cost of equity (CoE) to control for differences in the financial structure of the renewable and conventional power projects already described above.

Table 9 shows the average WACC before and after 2015, and Figure 5 the month-by-month WACC for the green and brown portfolios and the broad market. The cost of capital of all infrastructure investments has reduced over the past two decades due to increasing demand and the evolution of infrastructure investors' risk prefer-

Table 6: GMB performance, 2011-2021 (weighted least square regressions)

Panel A: 2011-2021

	DV = Green minus Brown 2011-2021								
	Model 1			Model 2			Model 3		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	-0.0001	(0.0013)	0.92209	-0.0021	(0.0011)	0.06229	-0.0029	(0.0012)	0.01597
broad_market_ew							0.0867	(0.0621)	0.16507
Size				-0.1816	(0.0508)	0.0005	-0.2233	(0.0605)	0.00033
Leverage				0.2924	(0.0879)	0.00115	0.2577	(0.0947)	0.00743
Profit				-0.0685	(0.0673)	0.31069	-0.0386	(0.0741)	0.60311
Investment				0.2895	(0.0757)	0.0002	0.28	(0.0739)	0.00023
Deg. freedom	127			127			126		
Adj-R2	0%			20.78%			21.26%		

Panel B: 2011-2015

	DV = Green minus Brown 2011-2015								
	Model 1			Model 2			Model 3		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	0.0025	(0.0024)	0.29782	-0.0032	(0.0015)	0.03613	-0.0031	(0.0019)	0.10449
broad_market_ew							-0.0023	(0.0957)	0.98097
Size				-0.349	(0.0742)	0.00002	-0.3479	(0.0951)	0.00058
Leverage				0.4921	(0.1366)	0.00068	0.4889	(0.145)	0.00139
Profit				-0.2237	(0.1185)	0.06432	-0.2275	(0.1443)	0.12075
Investment				0.4643	(0.1634)	0.0063	0.4607	(0.1647)	0.00711
Deg. freedom	57			55			54		
Adj-R2	0%			55.15%			53.93%		

Panel C: 2016-2021

	DV = Green minus Brown 2016-2021								
	Model 1			Model 2			Model 3		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	-0.0023	(0.0015)	0.11826	-0.0025	(0.0013)	0.06836	-0.0032	(0.0014)	0.0229
broad_market_ew							0.122	(0.08)	0.13208
Size				-0.0451	(0.0621)	0.47051	-0.1268	(0.0757)	0.0986
Leverage				0.007	(0.1202)	0.95367	0.042	(0.1267)	0.74112
Profit				-0.0358	(0.0768)	0.64242	0.0085	(0.0871)	0.92216
Investment				0.1545	(0.0872)	0.08111	0.1824	(0.0882)	0.04267
Deg. freedom	69			67			66		
Adj-R2	0%			2.16%			4.37%		

Source: infraMetrics®, calculations EDHEC*infra*

Table 7: Weighted Least Square Regression of the infraGreen portfolio, with (Panel A) and without (Panel B) the "Green minus Brown" effect

Panel A: infraGreen regression without GMB effect

	DV = infraGreen								
	2011-2021			2011-2015			2016-2021		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	-0.0005	(0.001)	0.63841	-0.0012	(0.0014)	0.39398	0.0009	(0.0013)	0.49875
broad_market_ew	1.0674	(0.0576)	0	0.9372	(0.071)	0	1.0283	(0.0844)	0
Size	-0.3502	(0.0552)	0	-0.3791	(0.0756)	0.00001	-0.1757	(0.073)	0.019
Leverage	0.3851	(0.0838)	0.00001	0.5072	(0.1032)	0.00001	0.2287	(0.1232)	0.06804
Profit	0.2098	(0.0788)	0.00878	-0.0332	(0.1033)	0.74926	0.2221	(0.0968)	0.02511
Investment	0.3071	(0.0648)	0.00001	0.3405	(0.1167)	0.00514	0.1802	(0.0638)	0.00628
Deg. freedom	124			54			64		
Adj-R2	86.58%			92.49%			93.53%		

Panel B: infraGreen regression with GMB effect

	DV = infraGreen								
	2011-2021			2011-2015			2016-2021		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	0.0012	(0.0009)	0.16386	0.0007	(0.0008)	0.38345	0.0016	(0.0012)	0.19829
broad_market_ew	0.9958	(0.0491)	0	0.9353	(0.0354)	0	0.9537	(0.0814)	0
Size	-0.2272	(0.0483)	0.00001	-0.1938	(0.0421)	0.00003	-0.0905	(0.0651)	0.16909
Leverage	0.2173	(0.0733)	0.00366	0.1729	(0.0636)	0.00885	0.2898	(0.1182)	0.01704
Profit	0.1839	(0.0653)	0.00567	0.0444	(0.055)	0.42289	0.339	(0.0817)	0.0001
Investment	0.143	(0.0568)	0.01316	0.0717	(0.0691)	0.30414	0.1266	(0.047)	0.00901
GMB	0.4497	(0.0638)	0	0.6005	(0.0506)	0	0.3429	(0.0902)	0.00033
Deg. freedom	123			53			63		
Adj-R2	91.94%			97.79%			95.37%		

Source: infraMetrics®, calculations EDHEC*infra*

Table 8: Weighted least square regression of the unlisted infrastructure brown power portfolio, with (Panel A) and without (Panel B) the "Green minus Brown" effect

Panel A: Brown power infrastructure regression without GMB effect

	DV = Brown power								
	2011-2021			2011-2015			2016-2021		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	0.0021	(0.0008)	0.00806	0.0023	(0.0011)	0.03737	0.0023	(0.0011)	0.04822
broad_market_ew	0.8944	(0.0251)	0	0.9193	(0.0351)	0	0.8778	(0.0437)	0
Size	-0.0749	(0.0264)	0.00536	-0.0325	(0.041)	0.43198	-0.129	(0.0446)	0.00516
Leverage	0.017	(0.0539)	0.75352	-0.0326	(0.0759)	0.66944	0.0804	(0.0839)	0.34163
Profit	0.0527	(0.0421)	0.21207	0.1138	(0.0649)	0.08536	0.0066	(0.0575)	0.90833
Investment	-0.0622	(0.0438)	0.15812	-0.0829	(0.0819)	0.31628	-0.0293	(0.0602)	0.62754
Deg. freedom	126			54			66		
Adj-R2	93.31%			94.85%			89.3%		

Panel B: Brown power infrastructure regression with GMB effect

	DV = Brown power								
	2011-2021			2011-2015			2016-2021		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	0.0008	(0.0005)	0.11973	0.001	(0.0008)	0.2142	0.0005	(0.0007)	0.49941
broad_market_ew	0.9321	(0.0198)	0	0.9409	(0.0272)	0	0.9287	(0.031)	0
Size	-0.1877	(0.0216)	0	-0.1631	(0.0349)	0.00002	-0.1827	(0.0302)	0
Leverage	0.1593	(0.0377)	0.00004	0.1296	(0.0577)	0.02904	0.1347	(0.0533)	0.01386
Profit	0.0311	(0.0295)	0.29325	0.0791	(0.0474)	0.10119	0.0044	(0.0368)	0.90482
Investment	0.0831	(0.0312)	0.00887	0.0707	(0.0624)	0.26283	0.0766	(0.0386)	0.05133
GMB	-0.4236	(0.0332)	0	-0.3389	(0.0446)	0	-0.5551	(0.053)	0
Deg. freedom	125			53			65		
Adj-R2	96.43%			97.32%			95.22%		

Source: infraMetrics®, calculations EDHEC*infra*

ences (risk pricing) when it comes to unlisted infrastructure equity.

However, the cost of capital of green infrastructure has decreased proportionately more than the market average and much more than that of brown infrastructure. In Figure 6, we also show the spread between the cost of capital of green and brown power over time. This spread of *green price premium* is consistently negative and has widened from around 100bp in 2011 to more than 350bp in 2021.

Figure 6 also shows that the spread between the cost of capital of green power shrank substantially during two periods, 2012-2015, and 2017-2019 (areas highlighted in grey). This shift is the result of the green power cost of capital decreasing faster than its brown equivalent. Thus, consistent with the evidence above, the reduction in the cost of capital or expected returns of green power infrastructure investments has led to significant capital gains i.e. realised returns and the performance of the GMB portfolio is largely explained by the evolution of a green price premium for renewable energy projects.

Table 10 shows that if we add the month-on-month change in the green price premium to the regression of the GMB portfolio factor returns, in the 2012-2015 period the intercept of the model is explained away (it is not significantly different from zero). As expected, the effect of the monthly change of the green price premium is negative; a positive change (a reduction) in the difference between the cost of capital of green and brown power reduces the returns of the GMB portfolio.

Table 9: Mean WACC in green and brown power infrastructure until 2015 and since 2016 and 2018.

	Green Power	Brown Power	Broad Market	t-test
Mean until 2015	0.074	0.087	0.085	-7.106
Mean since 2016	0.043	0.069	0.052	-34.828
Mean since 2018	0.042	0.072	0.051	-33.207

Source: infraMetrics®, calculations EDHEC*infra*, data as of December 2021 * t-test of the difference in mean between green and brown portfolios

Figure 5: Green and brown portfolio cost of capital

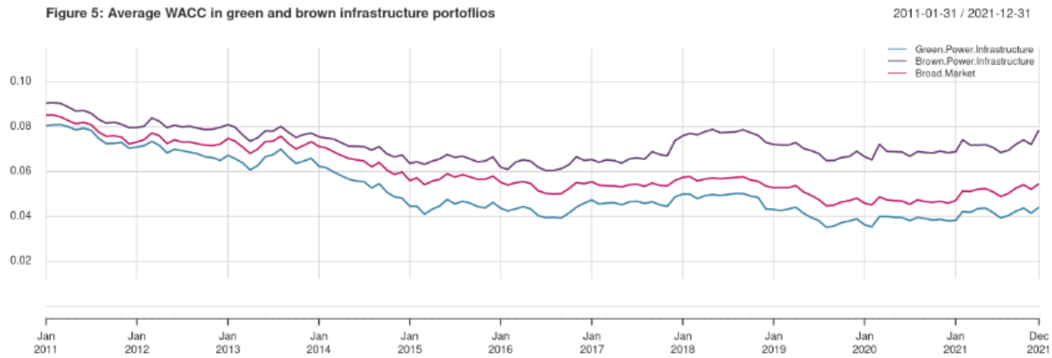


Figure 6: Green premium (spread) in the cost of capital of green and brown power portfolios

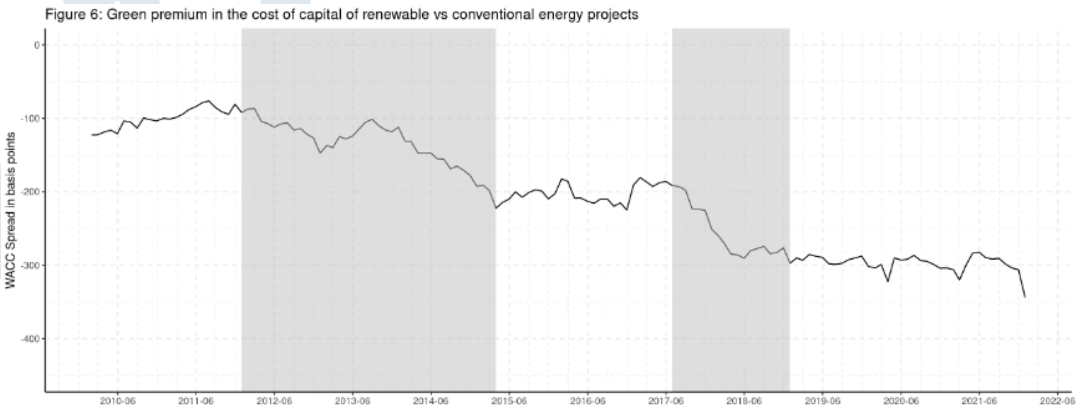


Table 10: WLS regression of the GMB portfolio excess returns including the effect of month-on-month changes in the green price premium

	DV = GMB								
	2011-2021			2011-2015			2016-2021		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	-0.0025	(0.001)	0.01502	-0.0031	(0.0016)	0.05668	-0.003	(0.0013)	0.02341
Size	-0.1666	(0.0478)	0.00067	-0.3505	(0.0818)	0.00008	-0.0557	(0.061)	0.36448
Leverage	0.2147	(0.0834)	0.01122	0.351	(0.1634)	0.03621	0.0301	(0.1186)	0.80042
Profit	-0.1214	(0.0629)	0.0558	-0.1474	(0.1203)	0.22591	-0.0865	(0.0783)	0.27346
Investment	0.2311	(0.0734)	0.00204	0.4386	(0.1652)	0.01039	0.1321	(0.0892)	0.1433
Green.Premium.Delta	-0.0005	(0.0001)	0.00001	-0.0005	(0.0002)	0.05552	-0.0004	(0.0001)	0.0023
Deg. freedom	126			54			66		
Adj-R2	33.07%			51.29%			14.8%		

Source: infraMetrics®, calculations EDHEC*infra*

5. Green Factor or Green Demand?

Near the equilibrium, asset prices can change because the remuneration of persistent risk factors changes, or because the exposure of individual assets to these factors changes. However, asset prices can also change because markets shift away from one equilibrium and towards another due to demand or supply shocks. The demand for green assets in a relatively new dimension of investors' preferences and portfolio decisions and it is reasonable to assume that while this demand barely existed two decades ago, it has been increasing ever since.

In the case of infrastructure in general and renewable energy in particular, asset prices have evolved significantly from a higher level of expected returns and lower asset prices to lower expected returns and higher prices ((see Blanc-Brude et al., 2021, for a discussion and empirical evidence of this 'great repricing' of infrastructure investments)). Regarding green vs brown power investments, we know that in the context of the energy transition, investors have been demanding more green energy assets and reducing their demand of less green (brown) energy assets in the expectation that they will lose value or become stranded following the introduction of carbon regulations.

To assess the impact of demand on the evolution of realised and expected returns in green and brown infrastructure, we build a proxy measure of excess demand for green assets using the share of secondary transactions in the global market for investing in green power assets. We consider a total of 6,109 investments made globally in solar and wind power projects between 2011 and 2021, representing a cumulative USD772bn of investment in 922GW of generation capacity. This data represents most of the investments made in renewable energy by private investors over that period. Some 2,904 of these investments were made in the secondary market i.e. they are not new or greenfield projects, and represent 545MW of capacity or USD228bn of investment.

Our proposed measure of the liquidity of the market for green power over time is the ratio of the value of secondary transactions (in MW of power or USD invested) to the total value of green transactions. The green power liquidity index shown on Figure 7 is the standardised, 12-month rolling mean of this ratio and suggests that the market for investing in green power assets underwent a significant evolution over the past decade. Between 2012 and 2015, liquidity is constrained and only 20% of investments by value and 40% by generation capacity are made in the secondary market. Liquidity then increases significantly over time to reach more than 60% in 2021 but goes through several through in 2018 and 2020. Table 11 shows that GMB excess returns, the green price premium (GMB WACC spread) and the excess returns of the green leg of the GMB portfolio (infraGreen) are largely related to movements in the liquidity of the market for green infrastructure equity investment.

Finally, we use the regression model in Table 10 to predict the returns of the GMB portfolio with the impact of the green price premium and, as a counterfactual, set this effect to zero. Figure 8 and 9 shows the rolling 12-month and cumulative returns of the GMB portfolio in both cases. When removing the impact of the green price premium i.e., of excess demand, we find the performance of the GMB portfolio is mostly negative. In other words, by removing the impact of yield compression (expected returns) which is itself largely correlated by excess demand, the historical outperformance of the GMB portfolio disappears.

Table 11: Regression of the GMB portfolio excess returns, GMB WACC Spread and green power excess returns against the green liquidity index

Panel A: 12-month rolling means

	GMB Excess Returns			GMB WACC Spread			InfraGreen Excess Returns		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	0.001	(0.0758)	0.98908	-0.1414	(0.0471)	0.00331	-0.0098	(0.0763)	0.89834
`Green Liquidity Index`	-0.9789	(0.1259)	0	-1.2268	(0.0783)	0	-1.1775	(0.1208)	0
Deg. freedom	115			115			115		
Adj-R2	33.88%			67.85%			44.78%		

Panel B: monthly values

	GMB Excess Returns			GMB WACC Spread			InfraGreen Excess Returns		
	Beta	SE	p.value	Beta	SE	p.value	Beta	SE	p.value
(Intercept)	0.0357	(0.0856)	0.67737	0.0009	(0.0738)	0.98991	0.023	(0.0854)	0.7881
GreenLiquidityIndex	-0.1925	(0.085)	0.02517	-0.5274	(0.071)	0	-0.1721	(0.0853)	0.04581
Deg. freedom	126			126			126		
Adj-R2	3.15%			29.89%			2.36%		

Source: infraMetrics®, calculations EDHEC*infra*

Figure 7: Green Liquidity Index

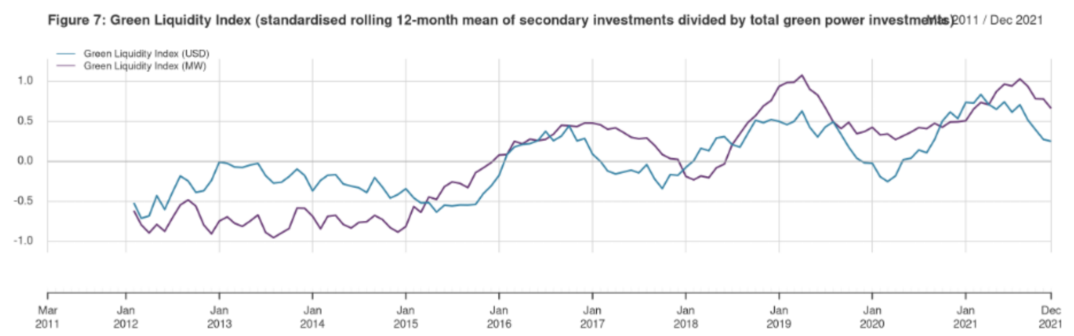


Figure 8: 12-month rolling GMB portfolio performance with and without the impact of excess demand

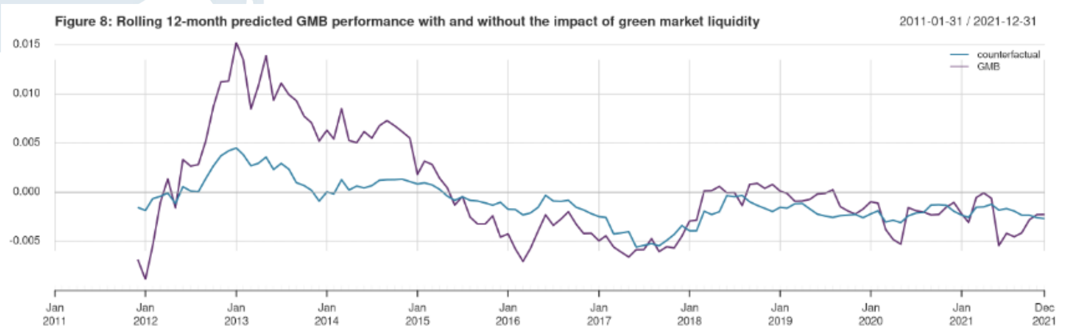
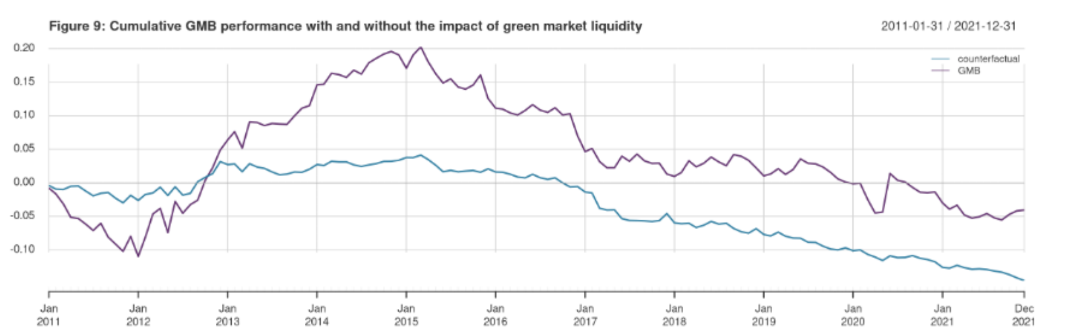


Figure 9: Cumulative GMB portoflio performance with and without the impact of excess demand



6. Conclusions

The premise that green investments may have different returns than brown ones partly springs from the notion of climate 'transition risk': the expectation of higher future costs or lower future revenues for firms that emit greenhouse gases due to new regulations and shifts in consumer behaviour. However, the manner, timing and magnitude with which transition risks may materialise have been and remain largely unknown to investors. Today, it can seem unlikely that asset prices already fully reflect these risks when they remain very hard to assess and quantify.

When it comes to renewable energy projects and their fossil-fuel (coal and gas) equivalents, however, the writing is already on the wall: wind and solar projects will be impervious to carbon taxes and coal and gas will not. In effect, coal projects are already being divested and phased out by large utilities, implying that their future value is considered to trend towards zero.

As we have shown, this knowledge already impacted asset prices in the case of green and brown power investments. The gradual realisation by investors that they have an increasing preference for green power investment and want to hold less conventional power investment has taken place over the past decade. In our 2022 survey of c.350 large investor portfolios of infrastructure assets, EDHEC*infra* found not only that renewable energy corresponds to between one quarter and one third of investors' infrastructure holdings by value at the end of 2021, but also that conventional gas and coal power projects represent as little as 1 to 3% of their portfolio, with the notable exception of North American investors who hold 10% of their infrastructure investments in brown power assets. In other words, brown power investments have largely been divested by mainstream investors already and green ones have already been integrated in portfolios on a significant scale. The shift in demand for green and brown power assets has already occurred.

One might add that higher demand for green power is not the only possible reason for the yield compression observed. For instance, infrastructure investment has been characterised by a significant evolution in the nature of investors valuing such assets, with the principal market increasing in size and scope and new cohorts of buyers and sellers showing increasing comfort with long-term, illiquid investments i.e., different risk preferences to previous generations of investors in infrastructure equity, who faced higher hurdle rates e.g., construction firms.

In 2011, green power projects had expected returns of ~8% and brown power projects ~9%. Their 10-year annualised total returns in 2021 were 16% and 17% respectively. These two figures may seem related but correspond in fact to very different economic fundamentals. We have shown above that the high historical performance of green power is explained by a significant compression in yields (expected returns) especially between 2012 and 2015 and the corresponding capital gains. Conversely, the performance of brown power was more driven by cash returns and less by yield compression. In effect, unlike other infrastructure investments, brown power investments have seen a slight increase in their expected returns since 2018.

Hence, we find that the impact on performance of such shifts in the demand for green and brown investments cannot be equated with the appearance of a new 'green' asset pricing risk factor. Instead, as predicted by theory (see Pastor et al., 2021), demand shocks have led to relatively high realised performance in the green power market but also lower expected returns.

For this situation to persist, there needs to be continued disagreement in the market about the future value of greener investments. The performance of green investments depends on the degree of agreement between investors about the long-term value of greener and browner investments. If this long-term value is uncertain, investors who prefer sustainable investment will overweight green assets and other underweight them, creating a temporary pricing anomaly. Once all investors agree about the future value of greener or less green investments, investors are left holding the market portfolio which includes current and future preferences for greener assets.

Going forward, as excess demand for green power investments is gradually met with additional supply of green power assets and effective allocations to green power become significant, our findings suggest that both the realised and expected returns of green power investments can be expected to converge.

Such a convergence, which reflects a long-term pricing equilibrium, leads us to conclude that there is no reason for superior performance by green infrastructure investments to continue. The so-called "green premium" observed in the past does not correspond to the remuneration of a superior risk factor but instead to a temporary phenomenon of excess demand, which the supply side of the market eventually satisfied.

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