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Measuring the impact of carbon transition risk on the equity performance of energy corporations[☆]

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ABSTRACT

This paper examines the financial impact of carbon transition risk on energy sector returns by constructing a green-minus-polluter (GMP) portfolio concentrating on the oil and gas (brown) corporations and utilities (green) across North America and Europe. A structural break in 2020 prompts a split analysis. Between 2014 and 2020, North American GMP portfolios show strong abnormal returns (9–10%), which turn negative in the 2021–2023 period. In Europe, zero-emission portfolios yield 6% abnormal returns initially but show no significant profitability afterward. These findings suggest a faster transition pace in North America and indicate that while green investing can help mitigate transition risk, its financial performance varies over time. Our findings also show that the GMP factor has stronger explanatory power in the North American market and among oil and gas companies, highlighting regional and sectoral differences. The study contributes to the ongoing debate on the benefits of aligning investments with the green energy transition.

1. Introduction

Fossil fuel-based energy production remains one of the primary contributors to climate change [1]. In response, international frameworks such as the Paris Agreement have set ambitious targets to limit the global average temperature rise to below 1.5°C. Achieving these goals has accelerated the global transition toward a low-carbon economy, prompting governments, corporations, and financial institutions to commit to net-zero emissions. As this transition unfolds, energy companies—particularly those in oil and gas—face mounting pressure to decarbonize. Carbon transition risk in the oil and gas sector can be reduced or diversified by investing in technology innovation and energy efficiency (Zhang et al., 2025).[1] Failure to substitute current technologies will result in termination [2]. Semieniuk et al. [3] show that the value of global stranded assets in the oil and gas sector could exceed $1 trillion dollars under possible shifts in expectations regarding climate policy impacts. This evidence shows that is of paramount importance to compare the adaptation process of oil and gas companies with cleaner power companies and analyze the asset pricing implications of the green transition in this relevant sector.

At the heart of this transition lies the concept of transition risk: the financial uncertainty arising from policy, technological, and market shifts linked to decarbonization. Measuring how this risk is priced in financial markets is critical to understanding investor behavior and corporate performance. A growing body of literature has explored the existence of a carbon premium—the idea that firms with higher carbon emissions compensate investors with higher returns due to greater exposure to transition risk [4,5]. Other models, such as those proposed by Pastor et al. [6,7], suggest that green assets should have lower expected returns because they act as hedges against climate risk. However,

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[1] This requires improving energy efficiency in injection, production gathering and transportation. Technology innovation requires also investment in renewable energy, hydrogen and carbon capture. Methods based on artificial intelligence can be used for emission monitoring.

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this view is challenged by studies that show realized and expected returns can diverge due to evolving investor preferences, climate policy, or mispricing of carbon risk (e.g., Ref. [8–10]). Hsu et al. [11] offer an alternative view suggesting that polluting firms may save cost by not investing in emission abatement in the short run, making them less exposed to climate related risk and more profitable than their green counterparts.

A related line of literature has highlighted the inefficiency concerning carbon risk pricing, arguing that the carbon risk premium does not appear to be accurately incorporated in market prices. This literature suggests that the risk associated with carbon emissions is underpriced, after controlling for other known risk factors in the literature, such as the market, size, value, and momentum factors (e.g., Ref. [12]; and references therein). Therefore, a carbon alpha could be delivered by taking long positions in green assets and short positions in brown ones. Shares of green companies in this context will provide an improved climate hedge and higher expected returns as the factor pricing theory predicts. In a related paper, Oestreich and Tsiakas [13] show that the long dirty and short clean strategy decreases in alpha over time. Other authors in the carbon risk literature demonstrate that investors may not require compensation for bearing carbon risk (e.g., Ref. [14,15], for the fixed income market). Gimeno and Gonzalez (2022) introduce a green factor based on green minus brown corporations and document a positive effect on portfolio returns for Europe and the US. In addition, some institutional research has compared the performance of green and fossil fuel stocks finding that there are superior risk-adjusted returns for renewable-related investments when compared to fossil fuels (the U.S. Energy Information Administration (EIA) report,2021[2]). Parker and Engle [16] present a method of identifying green and brown assets through their correlation with hedge portfolios representing various transition risks. Acharya et al. [17] introduce a general equilibrium model to analyze how climate transition risk affects valuations of different firms in the energy sector.

Despite the growing literature, a significant research gap remains: most studies rely on multi-sectoral data and pay limited attention to the energy sector—the largest single source of global greenhouse gas emissions. This gap is critical, as Parker and Engle [16] show sector-specific data is the most important factor in explaining transition risk exposure. Acharya et al. [17] demonstrate in an equilibrium framework that different transition risks results in different impacts on energy prices across time periods. However empirical evidence on how transition risk affects asset pricing within this sector—especially between high-emission oil and gas companies and low-emission utilities or renewable energy firms—is still limited. This study addresses this gap by examining the pricing of transition risk in the energy sector using a novel, sector-specific approach. We construct a green-minus-polluter (GMP) factor that captures differences in carbon transition risk between oil and gas companies (high-carbon intensity) and power utilities or renewable energy companies (low- or zero-carbon intensity). Our key innovation lies in using carbon intensity per unit of energy produced, sourced from the Transition Pathway Initiative (TPI), which offers a more accurate reflection of operational emissions in energy firms than traditional metrics based on firm size or revenue.

We pursue two main research objectives: (i) To assess whether and how financial markets are pricing transition risk within the energy sector; (ii) To quantify differences in investor responses between North American and European markets, and between oil and gas and power utilities firms.

Our contributions are threefold. First, we provide a novel empirical framework for pricing transition risk that accounts for the specific carbon exposure of energy companies. Second, we introduce a new transition risk metric—carbon intensity per energy output—which aligns closely with firm-level decarbonization strategies and industry benchmarks. Third, our GMP factor analysis reveals that transition risk pricing varies over time, with a structural break observed during the post-COVID recovery. This indicates that investor pricing of carbon risk is dynamic and influenced by external shocks and policy signals.

Furthermore, our results demonstrate that the GMP has generated higher alpha in the US than in Europe over the 2014–2020. It also offers greater explanatory power of equity returns in U.S. markets and among oil and gas firms compared to utility firms or European counterparts, suggesting regional and sectoral asymmetries in the transition to net zero. These findings not only extend the literature on carbon risk pricing but also offer practical implications for policymakers and investors, highlighting the need for targeted policy interventions to ensure the transformation of productive processes of oil and gas to green alternatives and to guarantee the profitability of green investments in the long run. Our work deepens the understanding about the effects of carbon transition risk by analyzing stock prices of oil and gas versus power corporations with highly different approaches towards carbon neutrality.

The remainder of the paper is organized as follows. Section 2 describes the regulatory differences along the green transition between Europe and North America. Section 3 provides a description of the data, the sample, and the construction of green-minus-polluter (GMP) Portfolio. In section 4 we dissect the GMP performance. In section 5 we analyze the extent to which GMP can explain the returns of the energy and power utilities portfolios. Section 6 makes discussion and conclusions.

2. The green transition in Europe versus North America

The transition to a low-carbon economy is progressing at different rates across regions, regulatory frameworks, and investor approaches. Therefore, the ability to make meaningful comparisons is essential. Table A1 in the appendix summarizes the main regulatory advances in support for the energy transition seen in Europe and the US from 2005. The EU ETS: Emission Trading System was launched in 2005 which placed Europe as a leader in the energy transition. The momentum for global green commitments took place in 2015 committing 196 parties plus the US to the Limit global warming to well below 2°C above pre-industrial levels, and pursue efforts to limit the increase to 1.5°C. The U.S. withdrew under President Trump in 2020 and rejoined under President Biden in 2021. It demonstrates that, while Europe has been a leader in setting green policies, the US is catching up due to its substantial investments in renewable energy. According to the *Global Trends in Renewable Energy Investment 2019*[3] report, the United States ranked second among the top twenty countries for renewable energy capacity investments between 2010 and mid-2019, investing $356 billion—-about 14% of the global total. In contrast, eight European countries appear on the same list, and Europe as a whole invested approximately $698 billion, representing around 28% of global investment.

A recent study by the European Stability Mechanism examines how the EU's Green Deal Industrial Plan and the US Inflation Reduction Act (IRA) differ in promoting decarbonization.[4] It contrasts Europe's emphasis on direct government investments with the US's focus on tax credits and subsidies, suggesting that while the US approach provides powerful incentives to transform supply chains the EU approach is better suited for stabilizing economic growth. In response to the COVID-19 pandemic, the EU launched the Next Generation EU (NGEU) programme, which later evolved into a key funding source for the Green Deal Industrial Plan through the Recovery and Resilience Facility and

[2] The full report is available at Annual Energy Outlook 2021 Narrative.

[3] The full report is available at Global Trends in Renewable Energy Investment 2019 | UNEP - UN Environment Programme.

[4] Document available at https://www.esm.europa.eu/blog/climate-change-and-industrial-transformation-different-approaches-europe-and-united-states?utm_source=chatgpt.com.

REPowerEU. Similarly, the US Inflation Reduction Act (IRA) aims to decarbonize the economy. While both initiatives are comparable in scale and objectives, they differ in approach: the EU relies on direct investments via loans and grants, whereas the U.S. uses indirect support through tax credits. These differences stem from institutional and political constraints. The EU lacks centralized tax authority, making grants and loans the primary tools. In contrast, U.S. political dynamics required the IRA to pass through budget reconciliation, limiting support to tax-related measures. The current paper addresses Canada as well as the US as a unified area labelled as North America. Canada's green policies share some similarities with the U.S., especially in their use of market mechanisms and reliance on fiscal incentives, but Canada also blends in more regulatory elements (such as it employs carbon pricing, regulatory mandates, and legislated climate targets) aligning it somewhere between the U.S. and the EU in approach.[5]

3. Data, sample, and methodology

3.1. Data and sample

We collect data on carbon emissions from Transition Pathway Initiative (TPI) for the companies located in Europe and North America which have particularly intensified scrutiny of emissions in the energy industry in recent years.[6] Data on carbon emissions are reported annually. Our sample starts in January 2014 and ends in December 2023. We focus on the high-polluting oil and gas companies in the energy sector, and their low-carbon power counterparties in the utilities sector. Alternatively, we use the renewable energy companies, identified under the Bloomberg Industry Classification Systems (BICS), as the substitute for the low-carbon power companies. These renewable energy companies are thought to be zero-carbon emitters which serve as an alternative counterpart to the high-polluting oil and gas companies. We restrict the renewable energy companies in our sample to have a market capitalization above USD 200 million to ensure stock liquidity and filter those companies that investors may not focus on, given their relatively low size.[7] Therefore, as is shown in Panel A of Table 1, our sample consists of 10 oil & gas companies and 21 power companies for Europe; 25 oil and gas companies, and 39 power companies for North America (US & Canada). In addition, the BICS delivers 33 and 16 renewable energy companies (zero emitters) located in Europe and North America, respectively.

Table 1
Summary statistics for the sample coverage and carbon emissions.

Panel A: The number of firms considered			
Geographical area and sector	Num. of firms	Low-carbon GMP	Zero-emitting GMP
European oil and gas	10	10	10
European power	21	10	
European zero emitters	33		10
North American oil and gas	25	25	12
North American power	39	25	
North American zero emitters	16		12

Panel B: The descriptive statistics of carbon emission intensity				
Geographical area and sector	Mean	Stdev	Max	Min
European oil and gas	68.65	3.98	75.22	58.65
European power	36.97	24.29	92.67	2.78
North American oil and gas	74.38	6.63	97.40	56.44
North American power	59.73	48.08	161.11	8.33

This table reports in Panel A the number of firms covered by the database of Transition Pathway Initiative (TPI) providing carbon emissions data for the 2014–2023 period. To be specific, the number of firms actually used to construct different versions of GMPs is also reported in Panel A. The descriptive statistics of carbon intensity are reported for the oil and gas and the power utilities sectors in both North America and Europe in Panel B. Source: Authors' calculations based on Factset data.

To measure carbon transition risk, emission intensity is applied for each firm as carbon emissions scaled by their energy production, which is described as follows:

$$\text{Emission intensity} = \text{Carbon Emissions} / \text{Energy production} \qquad (1)$$

We use an emissions intensity metric based on the Greenhouse Gas Protocol to standardize carbon emissions. This approach converts absolute emissions into a metric that reflects the level of activity in each sector. For the oil and gas sector, the relevant activity is the amount of energy produced and sold externally, and the emission intensity is expressed in grams of CO_2 equivalent per megajoule (gCO_2-e/MJ). For the power utilities sector, activity is measured as energy produced in megawatt-hours (MWh) and emission intensity in metric tons of CO_2 equivalent per megawatt-hours ($MtCO_2$-e/MWh).

The methodology we use is consistent with the Science Based Targets initiative (SBTi)[8] and is also followed by the International Energy Agency (IEA) to stablish benchmarks and targets. This requires incorporating scopes 1, 2, and 3 in the construction of the emissions intensity variable for oil and gas companies while only considering electricity generation for power corporations. To homogenize the unit of measurement, we transform the emission intensity of power companies measured in metric tons of CO2 equivalent per megawatt hour to grams of CO2 equivalent per megajoule using the conversion factor of 1×10^6 divided by 3600.

3.2. Sector classification under the Science Based Targets initiative

The Science Based Targets initiative (SBTi) classifies the oil and gas (O&G) sector based on the framework developed by IPIECA, the global oil and gas industry association established at the request of the United Nations Environment Programme. According to IPIECA (2021), the sector is divided into three main segments: upstream (exploration, drilling, production, and field services), midstream (pipelines, terminals, maritime transport, and storage), and downstream (refining, retail distribution, petrochemicals, and natural gas distribution). However, SBTi excludes certain activities from its emissions assessment methodology due to their relatively minor contributions to overall greenhouse gas emissions. These include O&G services and logistics, which lack decision-making authority over emissions-related investments; transportation and storage, which account for only about 1% of sector emissions; and O&G trading, which is not considered a significant driver of emissions reduction.

[5] Canada's 2023 budget introduced measures to match the U.S. Inflation Reduction Act (IRA).

[6] See Page 34 "The Oil and Gas Industry in Energy Transitions" IEA 2020.

[7] Our methodology is aligned with the IEA and the Centre for Climate Finance & Investment (2021) analysis of Clean Energy companies. Full article is available at: Clean Energy Investing: Globla Comparison of Investment Returns.

[8] The Science based targets initiative (SBTi) is developed to stablish targets in different sectors to reduce their greenhouse gas emissions. SBTi is a partnership between Carbon Disclosure Project (CDP), the United Nations Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF), that establish guidance on setting science-based targets for Oil, Gas and Integrated Energy companies.

Carbon emissions within the sector are measured in line with the Greenhouse Gas Protocol, the most widely used accounting framework for corporate emissions. This protocol distinguishes among Scope 1 (direct operational emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (indirect emissions across the value chain, such as end-user fuel combustion). While reporting of Scope 1 and 2 emissions is mandatory under the Corporate Standard, Scope 3 reporting is voluntary, as defined by the Corporate Value Chain Accounting and Reporting Standard.

Based on these classifications, the analysis constructs a portfolio of oil and gas companies in Europe and North America consistent with SBTi criteria, focusing on firms whose operations significantly contribute to sectoral emissions. This includes two groups: "Majors" (large, integrated international oil companies listed in the US and Europe) and "Independents" (smaller companies focused on upstream operations or fully integrated but smaller in scale). Carbon emissions intensity data for these firms are sourced from the Transition Pathway Initiative (TPI), which provides standardized benchmarks across Scopes 1, 2, and 3 to offer a comprehensive view of sector emissions.

This study uses an emissions intensity metric based on the Greenhouse Gas Protocol, measuring carbon emissions per unit of energy produced to standardize emissions across firms. This method, also used by the Transition Pathway Initiative (TPI), allows for consistent benchmarking in the oil & gas and power utilities sectors. For oil and gas, emissions are expressed in gCO_2-e/MJ based on external energy sold; for power utilities, energy output (originally in MWh) is converted to MJ for comparability.

While some studies (e.g., Ref. [18]) scale emissions by firm sales to compare companies across sectors, this paper argues that scaling by energy production is more appropriate for these two sectors, where emissions are closely tied to operational output. This approach aligns with the assumption that emissions rise linearly with output (e.g., Ref. [19]). Though other methods (e.g., emissions per revenue or market cap) exist in the literature, the chosen metric—emissions per energy produced—is considered the most accurate and relevant for assessing carbon intensity in energy-focused industries.

In parallel, the analysis of the power utility sector follows the International Energy Agency (IEA) approach, evaluating emissions strictly from electricity generation. Although many utilities companies are involved in distribution, retail, or gas-related activities, this generation-focused method captures the majority of emissions in the sector. Emissions intensity data for power utilities are also drawn from TPI, which, in alignment with IEA criteria, considers Scope 1 emissions only.

3.3. The construction of green-minus-polluter (GMP) portfolio

To construct the green-minus-polluter (GMP) portfolio, we collect from FactSet the daily stock prices of the sample firms. In this study, power companies in the utilities sector are grouped into the green portfolio, while oil and gas companies in the energy sector are used to form the polluter portfolio. As the number of power companies is greater than that of the oil and gas companies, we follow the empirical asset pricing literature and incorporate an identical number of companies for building the green and polluter portfolios.[9] Specifically, there are 10 oil and gas companies in Europe; we thus sort the European power companies by their carbon intensity and pick the top 10 with the lowest intensity, as considered to be the greenest ones in our sample. The same method is applied to North American firms. While there are 25 North American oil and gas companies in the sample, we select the same number of power companies with the lowest carbon intensity. After that, we build four equal-weighted portfolios, i.e., green NA, polluter NA, green EU, and polluter EU. The choice of equal weighting follows the work of Bauer et al. [10] who argue that using equal-weighted returns reduces the influence of very large firms which tend to dominate value weighted portfolio returns.[10] As carbon intensity varies over time, the components of green portfolios for both North America and Europe should be adjusted every year according to their greenness. In other words, we recalibrate the green portfolios every year while the polluter portfolios remain unchanged. Finally, the green-minus-polluter (GMP) portfolio is built as a long-short portfolio that is long on the green portfolio and short on the polluter portfolio.

As mentioned above, we alternatively consider the renewable energy companies as zero-carbon emitters when building the green portfolio and accordingly the GMP. The BICS identifies 16 corporations in North America. After dropping firms with missing data, we finally have 12 zero-emitting firms. We thus select the 12 most polluted firms from the sample of 25 North American oil and gas companies on a yearly basis based on their carbon intensity. The case for the EU is different. Given that there are only 10 EU oil and gas firms in our sample, we then choose 10 zero emitters (from an initial sample of 33 firms) according to their market capitalization because they cannot be ranked in terms of carbon emissions. As such, we build the GMP in an alternative way by using the zero-emitting companies as the components of green portfolios. As a mean of robustness, this alternative GMP may unveil the effect of different speeds of transition on portfolio returns.

In Table 1, we summarize the actual number of companies used for constructing the two versions of GMP in the last two columns of Panel A. To depict the carbon performance of the three sectors-oil and gas, power, and zero emitter-involved in this study, we provide their emission distributions in Panel B of Table 1. It is shown that oil and gas companies indeed have a higher carbon intensity on average relative to power companies in both NA and EU. Noth that oil and gas companies exhibit a similar magnitude of carbon intensities within region while the carbon performance of power companies is diverse with a large standard deviation and a big difference between the maximum and minimum values.

4. The anatomy of green-minus-polluter (GMP) portfolio

4.1. The evolution of GMP

In what follows, we examine the profitability of GMP. Fig. 1 displays the cumulative returns of GMP in Europe and North America across the entire sample period 2014–2023. Looking at Panel A, the first insight is that there appears to be a change of trajectory in the evolution of the GMP around the COVID-19 crisis. Up to 2020 there is a clear outperformance of the North American GMP (NA-GMP) portfolio signaling that green investments were delivering greater return to investors than their brown counterparts. This pattern changes after March 2020 and the NA-GMP experiences a persistent downward trend since November 2020 and even exhibits negative values after September 2021. Such a significant shift may be related to the financial market reactions to the US's formal withdrawal from the Paris Agreement under the Trump administration in November 2020. The European GMP (EU-GMP) generated negative returns between May 2015 and March 2020. Following a brief recovery, a renewed downward trend emerged after November 2020, which may be attributed to factors such as the rollout of COVID-19 vaccines, the unexpectedly rapid recovery of global stock markets, and the subsequent energy crisis triggered by the Russia–Ukraine war. Such a change of trajectory is not as strong as that observed in the US market. This could be attributed to the European

[9] In the empirical asset pricing literature, it is common to build the spread of tertile/quintile/decile portfolios and examine whether this high-minus-low portfolio delivers significant returns.

[10] The choice of equal-weighted portfolio ensures that performance is independent of market capitalization by mitigating size bias, allowing returns to reflect each firm's contribution equally and enabling a performance assessment based solely on return data [16].

Union's ambitious policy initiatives, such as the European Green Deal[11] introduced in December 2019.

The COVID-19 crisis enhanced the profitability of the GMP in both geographical areas highlighting the hedging properties of green assets in times of demand driven crises. This is related to the collapse of stock prices in oil and gas corporations during the COVID-19 crisis. The opposite effect takes place during the 2021–2022 European energy shock in which gas supply sources are drastically restricted leading to escalating gas and oil prices. While the European gas benchmark increased by a 10-fold and the crude oil prices almost doubled (e.g., Ref. [20,21], about an analysis of the European Energy Crisis). The two benchmark GMPs appear to exhibit substantial volatility over the sample period. This may be largely attributed to fluctuations in fossil fuel prices, but may also reflect shifts in public concern about climate change. This interpretation is consistent with Pastor et al. (2022), who argue that the outperformance of green stocks is closely linked to rising public interest in climate-related issues. Such interest intensified around key policy developments, including the introduction of the European Green Deal in December 2019 and the EU Recovery Plan ("Next Generation EU") in November 2020. As previously noted, both GMPs demonstrated stronger performance in the immediate aftermath of the COVID-19 crisis compared to earlier years.

However, the post-COVID decline in GMP performance in both Europe and the US may also be tied to increasingly stringent green regulatory frameworks. These intensified following the onset of the Russia–Ukraine war, particularly through initiatives such as REPowerEU in the European Union and the Inflation Reduction Act in the United States. The slower-than-anticipated pace of the energy transition has amplified investor concerns about exposure to fossil fuel import risks and energy price volatility [22]. Moreover, the accelerating complexity of sustainability regulations has posed significant challenges, particularly for asset managers and financial intermediaries, arguably more so than for the companies subject to these regulations. Since the introduction of the Sustainable Finance Disclosure Regulation (SFDR) in the EU in 2021, asset managers have been required to classify and disclose their investments based on sustainability criteria, adding further regulatory pressure to the financial sector.

This figure plots the cumulative returns (in percentage) of GMP in both North America (blue line) and Europe (orange line) regions. GMP in Panel A is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies, while GMP in Panel B is built as a portfolio going long on renewable energy companies regarded as zero-carbon emitters and short on polluting oil and gas companies. The sample period is from January 1st, 2014 to December 31st, 2023. Source: Authors' calculations based on Factset data.

The time series evolution of GMP constructed with the zero-emitters is illustrated in Panel B of Fig. 1. A close inspection of this figure suggests that cumulative returns are on average much higher than the profitability of GMP illustrated in Panel A for both NA and EU. This is expected since renewable energy companies viewed as zero-carbon emitters should perform better than those companies belonging to the power sector, as they are normally growth (rather than value) corporations. This implies that they will trade with higher multiples. While the cumulative returns of both GMPs for zero emitters declines after November 2020, the decrease is more moderated than that under the low-carbon counterpart. In fact, the EU-GMP evolves with positive profitability from May 2017 towards the end of the sample period. Moreover, cumulative returns are negative in the case of EU for a shorter period (namely, November 2015–May 2017) compared to Panel A of Fig. 1 which exhibits negative returns from January 2015 to March 2020.

The performance of the zero-emitting EU-GMP significantly increased and moved closer to the GMP performance of NA since 2018, indicating that the effect of green transition is captured in the stock prices. This could be attributed to several circumstances in Europe and North America. In 2018, the European Union Commission unveiled its Action Plan on Sustainable Finance, a strategy aimed to channel capital flows towards sustainable investments. This initiative coincided with a contrasting trend in US policy, where following the start of the US Fed rate increases in 2017, the Trump administration announced its withdrawal from the Paris Agreement in June of that year, and subsequently approved oil and gas developments, such as drilling in the Arctic or building new pipelines between Canada and the US. By contrast, the European green regulation advanced introducing the EU taxonomy and the Sustainable Financial Disclosure Regulation in 2020. Although the process of green transition faced great difficulties, Panel B of Fig. 1 shows that both GMP portfolios reached almost the same total returns (approximately equal to 140%) during and in the aftermath of the COVID-19 pandemic, due to risk exposures to a common energy shock under a faster than expected post-COVID recovery.

The results reported for the GMP portfolio in this study align with those of Gimeno and González [23], who also find increasing returns over time during the 2015–2020 period. However, while Gimeno and González [23] observe a high degree of similarity in the evolution of the EU and US portfolios over their broader 2002–2021 sample—based on a cross-sectional GMP approach—our findings indicate that convergence between the two regional portfolios becomes apparent only from 2020 onward. This suggests that when sectoral diversification is applied, as in cross-sectional analyses, the US and EU GMP portfolios tend to evolve similarly due to the smoothing of idiosyncratic sector-level differences. In contrast, when focusing specifically on the energy sector, as in the present analysis, regional disparities become more pronounced. This divergence is consistent with the findings of Pickl [24], who categorizes oil majors as either renewable leaders or laggards, and demonstrates that European oil companies are at the forefront of renewable energy investment, whereas their US counterparts have generally lagged behind.

Notably, Panel B of Fig. 1 illustrates a clear shift in the trajectory of the zero-emitting NA-GMP after 2020, showing a persistent downward trend with a maximum drawdown of approximately 170%. In contrast, the change in trajectory for the zero-emitting EU-GMP is comparatively moderate. While both the ongoing effects of the COVID-19 crisis and the subsequent outbreak of the Russian–Ukrainian conflict served as common shocks that generally supported the case for renewable energy, the divergent policy approaches have led to markedly different market responses. In particular, the United States' inconsistent stance on the green transition stands in stark contrast to the European Union's steady commitment to sustainability leadership—differences that are clearly reflected in the behavior of the respective GMPs.

4.2. Summary statistics of GMP profitability and structural break tests

In this subsection, we examine the effect of carbon emissions intensity on same-year returns of GMP portfolios. The return distributions of GMP for the whole sample period are summarized in Table 2a. Panel A shows that the average profitability of GMP is negative and not statistically significant for both NA and EU. Lower mean returns and Sharpe ratios are reported for the US. Results shown in Panel B demonstrate that GMP portfolios based on zero-emitters deliver positive outperformance in EU. However mean values are only significant at the 12% level.[12]

Reported results in the previous subsection suggest that the evolution of the GMP factor may be affected by structural breaks. In what follows, we apply the Bai-Perron (2003) methodology to formally test for this

[11] Reference: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

[12] While Shape Ratios change from −0.22 to −0.08 for NA, the improvement is from −0.11 to 0.47 in the case of Europe. However, this improvement is limited as mean values are not statistically significant.

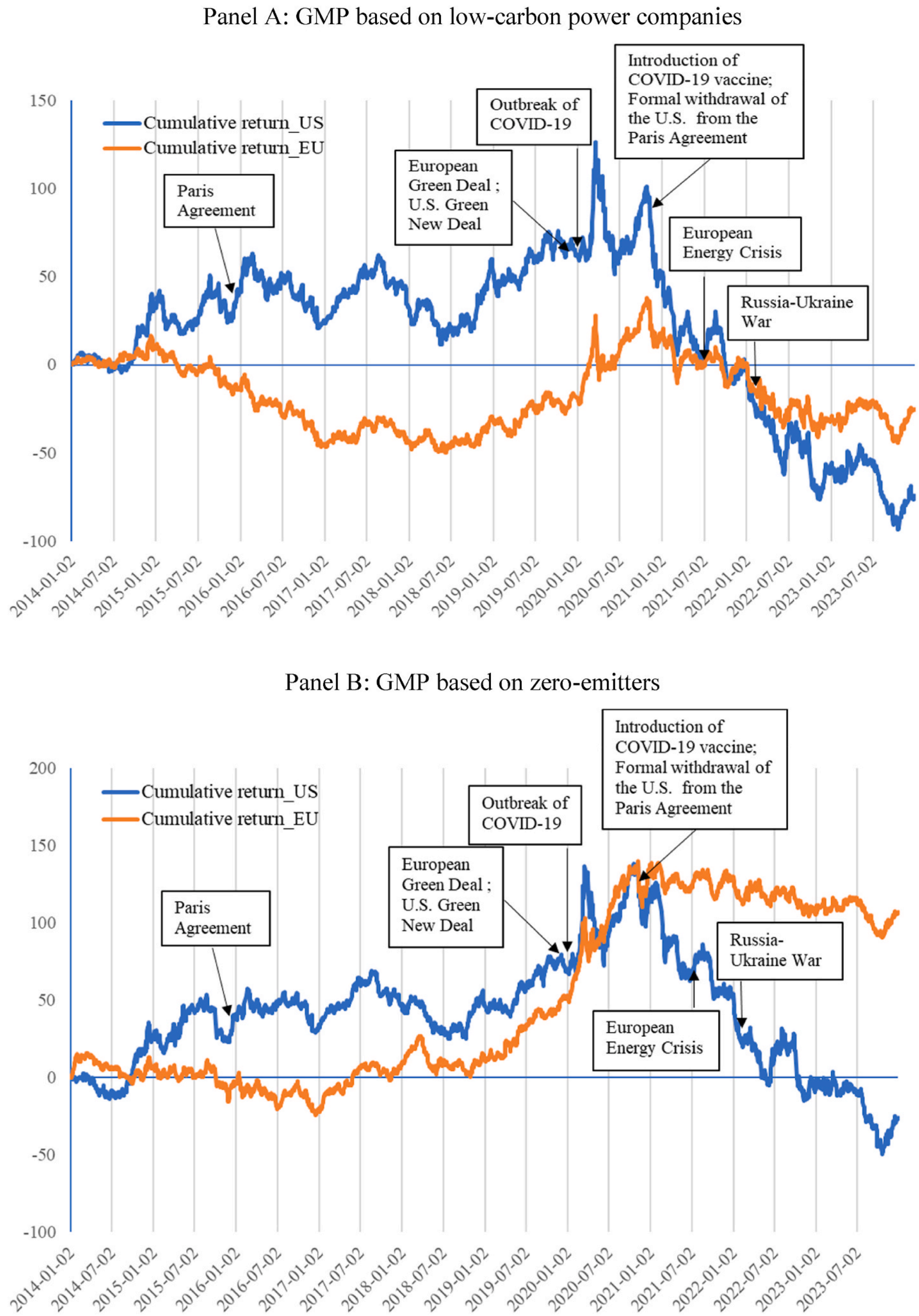

Fig. 1. The cumulative return of GMP.

possibility. Structural break results are reported in the last panel of Table 2a. They show that, the NA-GMP factor exhibits a structural break dated in March 19, 2020 for the low-carbon case, and a break dated in November 9, 2020 for the zero-emitting case. In comparison, the EU-GMP factor rejects the null hypothesis of a structural break under both measurements of GMP. While the first break dated in the NA-GMP coincides with the start of the COVID-19 crisis, the second break shown in the zero-emitters corresponds to the introduction of the vaccines in November 2020 and the start of the post-COVID recovery. The existence of two breaks in 2020 motivates the analysis of the GMP factor performed in two subsamples, namely 2014–2020 and 2021–2023, in addition to the whole 2014–2023 sample period.

The return distributions of GMP for the 2014–2020 period are summarized in Table 2b. Panel A shows that the average profitability of GMP is significantly positive for both NA and EU. Results reported in Panel B are more impressive. GMP portfolios based on zero-emitters deliver substantial outperformance with respect to the counterparts constructed with low-carbon power companies for both regions. This finding is consistent with the fact that increasing climate change awareness in the last years has shifted investors' demand towards greener assets. The improved performance arises from significantly higher average returns. The portfolio returns on average increase from 7.81% to 2.65%–20.44% and 20.66% in NA and EU, respectively. Given similar volatilities are documented under both measures of GMP, the Sharpe ratios[13] increase significantly to 0.67 and 0.87 for the case of NA and EU, respectively.

[13] This is the simplest measure of risk-adjusted returns [10]. It is a commonly used metric of financial performance in the literature (for instance Ref. [11]), which measures average abnormal returns per unit of risk measured as the standard deviation of returns.

Table 2a
Descriptive statistics of the return distributions and structural break tests for GMP (2014–2023).

Panel A: GMP based on low-carbon power companies							
	Mean	Stdev	Skew	Kurtosis	Max	Min	Sharpe
NA	−7.66 (-0.68)	34.92	−0.16	9.69	21.56	−16.89	−0.22
EU	−2.60 (-0.35)	22.83	−0.45	6.13	10.32	−9.82	−0.11
Panel B: GMP based on zero-emitters							
	Mean	Stdev	Skew	Kurtosis	Max	Min	Sharpe
NA	−2.75 (-0.24)	35.64	−0.40	10.66	20.51	−18.70	−0.08
EU	11.02 (1.46)	23.44	−0.50	7.33	10.89	−13.90	0.47

Panel C: Structural break tests	Break date	F-statistics	Significant level
Low-carbon NA-GMP	2020/3/19	8.95	5 %
Low-carbon EU-GMP	No break	2.21	Not significant
Zero-emitting NA-GMP	2020/11/9	9.29	5 %
Zero-emitting EU-GMP	No break	3.32	Not significant

This table reports in Panel A and B, the (annualized) mean return, the (annualized) standard deviation, skew, kurtosis, the maximum and minimum daily return, and the (annualized) Sharpe ratios for GMP in North America and Europe. Panel C reports the results of structural break tests. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023.
Source: Authors' calculations based on Factset data.

Table 2b
Descriptive statistics of the return distributions for GMP (2014–2020).

	Mean	Stdev	Skew	Kurtosis	Max	Min	Sharpe
Panel A: GMP based on low-carbon power companies							
NA	7.81* (1.72)	33.93	−0.04	13.67	21.56	−16.89	0.23
EU	2.65* (1.68)	20.87	−0.54	8.46	10.32	−9.82	0.13
Panel B: GMP based on zero-emitters							
NA	20.44* (1.74)	30.58	−0.26	11.53	14.30	−18.10	0.67
EU	20.66** (2.27)	23.72	−0.96	12.13	10.89	−13.90	0.87

This table reports the (annualized) mean return, the (annualized) standard deviation, skew, kurtosis, the maximum and minimum daily return, and the (annualized) Sharpe ratios for GMP in North America and Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

Table 2c
Descriptive statistics of the return distributions for GMP (2021–2023).

	Mean	Stdev	Skew	Kurtosis	Max	Min	Sharpe
Panel A: GMP based on low-carbon power companies							
NA	−43.98** (-2.02)	37.06	−0.35	2.95	9.16	−14.86	−1.19
EU	−14.93 (-0.94)	26.88	−0.31	3.17	7.61	−8.44	−0.56
Panel B: GMP based on zero-emitters							
NA	−50.84** (-2.24)	38.60	−0.81	5.62	8.88	−18.56	−1.32
EU	−10.86 (-0.76)	24.27	−0.15	1.27	5.71	−6.05	−0.45

This table reports the (annualized) mean return, the (annualized) standard deviation, skew, kurtosis, the maximum and minimum daily return, and the (annualized) Sharpe ratios for GMP in North America and Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2021–2023. Source: Authors' calculations based on Factset data.

Although the Sharpe ratios observed for the low-carbon GMP portfolio do not surpass those reported in prior studies (e.g., Ref. [10]), the zero-emitting portfolios clearly outperform the benchmarks found in the literature. Specifically, while Bauer et al. [10] report Sharpe ratios between −0.20 and −0.65 for the brown-minus-green (BMG) portfolios, our analysis of zero-emitting portfolios yields Sharpe ratios ranging from 0.67 to 0.87 for the 2014–2020 sample. It is important to note, however, that the proposed GMP portfolio exhibits higher volatility than those found in earlier studies. This is largely attributable to our focus on the energy sector, in contrast to the broader, multi-sector approaches used in the literature. Overall, the strong performance of the GMP portfolios during the first subsample aligns with existing empirical evidence on the return differentials between green and brown assets (e.g., Ref. [23,26]; Pastor et al., 2022).

The next step is to analyze the GMP performance during the 2021–2023 period. Note that this subsample covers the faster than expected post-COVID recovery as well as the European energy crisis. During this period, oil and gas prices soared due to restricted supply of energy flows from Russia. The performance of the GMP factor shows significant deterioration in the North American portfolios, with notably negative returns under both low-carbon and zero-emitting strategies. In contrast, the EU-GMP portfolios also exhibit negative returns, though these are not statistically significant.(see Table 2c)

This subsample period is characterized by high energy prices transited into high profitability in the oil and gas corporations. The lower green performance may have been also affected by a global decline in interest in the sustainability agenda. The reality for many businesses—especially in capital-intensive industries—is that sustainability commitments often translate into higher costs, regulatory burdens, and reduced financial flexibility. High emitters may save cost by not investing in emission abatement and environmental recover in the short run [11]. Moreover, companies and investment funds may re-evaluate their sustainability commitments due to changing political and economic factors, particularly the on-going war in Ukraine. The evidence of reduced greenium after 2021 is advocated by Eskildsen et al. [27], Grishunin et al. [28], and among others, in terms of both stock and bond markets. They claim that this empirical fact can be associated to a number of potential factors including green market saturation, rising interest rates, higher geopolitical risks, and a general decline in interest in the sustainable development agenda amid fears of greenwashing [28]. The situation has worsened with the recent return of Donald Trump to the U.S. presidency. Examples of this process include companies such as Porsche or Volkswagen reconsidering electrification strategies. In contrast, the EU exhibits stronger commitments and efforts on promoting renewable energies. It tries to be a pioneer in the sustainable development exemplified by ambitious policy initiatives, such as the Sustainable Finance Disclosure Regulation (SFDR) in 2021, and the REPowerEU initiative in 2022 in tackle with the energy crisis caused by the Russian–Ukrainian conflict.

4.3. Explaining the GMP

We next proceed to analyze the extent to which the GMP portfolio generates alpha. We run a regression of the log return of GMP on the Fama-French [29] three factors and the momentum factor of Carhart [30]. The descriptive statistics of the four risk factors are provided in Table A2 in the appendix. As was reported in the previous section, results vary substantially across subsamples, which are displayed in Tables 3a, 3b and 3c for the whole sample and the two subsamples. When considering the 2014–2023 period, we can see that there is not a statistically significant alpha reported for the NA or EU under the low-carbon and zero-emitting GMP specifications. Coefficients are negative for the low-carbon GMPs while they are positive for the zero-emitting ones. Reported results do however demonstrate that the GMP factor can be explained by the factors commonly used in the literature, as all coefficients are statistically significant apart from the coefficient corresponding to the market factor in the zero emitters version of the EU-GMP. Overall, the results reported above suggest that the GMP doesn't generate abnormal return in a longer time-span, which is absorbed by those well-established pricing factors.

Results for the 2014–2020 period are reported in Table 3b. These are notoriously different from those reported for the whole sample. In fact, a strong GMP performance is reported demonstrating that the profitability of GMP cannot be explained by the common risk factors prominent in the asset pricing literature. Specifically, the GMP portfolio delivers positive abnormal returns for both portfolios in NA. Estimated alphas are statistically significant and equal to 9% (*t-statistics* = 2.08) and 10% (*t-statistics* = 2.42) for the low-carbon power and zero-emitters based portfolios, respectively. In the case of EU, only the zero-emitters based GMP portfolio delivers a significant alpha, the four-factor adjusted return equal to 6% (*t-statistics* = 2.09). This finding suggests that GMP captures the unique information about carbon transition and that there are different paces of carbon transition between both areas.

Table 3a
Regression of the GMP returns on the four-factor model (2014–2023).

Panel A: GMP based on low-carbon power companies				
	NA	t-stats	EU	t-stats
Alpha	−0.01	−0.29	−0.01	−0.42
Mkt-RF	−0.48***	−13.88	−0.18***	−6.48
SMB	−0.54***	−8.64	0.12*	1.82
HML	−0.91***	−19.70	−1.09***	−21.73
MOM	0.18***	4.58	−0.04	−1.00
Adj. R^2	0.26		0.21	
Panel B: GMP based on zero-emitters				
	NA	t-stats	EU	t-stats
Alpha	0.003	0.07	0.03	1.30
Mkt-RF	−0.41***	−11.29	0.01	0.26
SMB	0.12*	1.80	0.68***	9.76
HML	−1.02***	−20.95	−0.98***	−19.35
MOM	0.17***	4.32	0.15***	3.73
Adj. R^2	0.22		0.23	

Regression of the returns of the GMP (green-minus-polluter) against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors. The *t-statistics* based on Newey and West [25] standard errors are reported. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

Table 3b
Regression of the GMP returns on the four-factor model (2014–2020).

Panel A: GMP based on low-carbon power companies				
	NA	t-stats	EU	t-stats
Alpha	0.09**	2.08	0.01	0.41
Mkt-RF	−0.53***	−14.35	−0.17***	−5.40
SMB	−0.45***	−6.21	0.12*	1.71
HML	−0.18**	−2.47	−0.76***	−10.71
MOM	0.67***	11.89	0.10**	2.02
Adj. R^2	0.31		0.19	
Panel B: GMP based on zero-emitters				
	NA	t-stats	EU	t-stats
Alpha	0.10**	2.42	0.06**	2.09
Mkt-RF	−0.37***	−10.11	0.13***	3.80
SMB	0.17**	2.40	0.80***	9.96
HML	−0.20***	−2.84	−0.72***	−9.00
MOM	0.72***	13.05	0.26***	4.79
Adj. R^2	0.26		0.19	

Regression of the returns of the GMP (green-minus-polluter) against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors. The *t-statistics* based on Newey and West [25] standard errors are reported. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

Table 3c
Regression of the GMP returns on the four-factor model (2021–2023).

Panel A: GMP based on low-carbon power companies				
	NA	t-stats	EU	t-stats
Alpha	−0.14*	−1.85	−0.01	−0.11
Mkt-RF	−0.53***	−7.06	−0.18***	−3.42
SMB	−0.54***	−4.95	−0.27*	−1.72
HML	−0.93***	−12.08	−1.14***	−13.09
MOM	−0.34***	−5.08	−0.34***	−4.36
Adj. R^2	0.24		0.22	
Panel B: GMP based on zero-emitters				
	NA	t-stats	EU	t-stats
Alpha	−0.14*	−1.82	0.02	0.38
Mkt-RF	−0.56***	−7.22	−0.26***	−5.77
SMB	0.35***	3.16	0.08	0.56
HML	−1.15***	−14.38	−1.19***	−15.95
MOM	−0.27***	−3.86	−0.20***	−2.98
Adj. R^2	0.27		0.29	

Regression of the returns of the GMP (green-minus-polluter) against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors. The *t-statistics* based on Newey and West [25] standard errors are reported. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2021–2023. Source: Authors' calculations based on Factset data.

Note that the outperformance of the NA-GMP portfolio is not anticipated a priori given that Europe has historically been more proactive and timely[14] in introducing regulation changes for green transition compare to North America.[15] However, while regulation in Europe has focused on direct government investments, the US's emphasis has been on tax credits and subsidies. Reported results therefore suggest that the US approach has provided powerful incentives to transform supply chains and innovation. This is consistent with the 2024 report of the International Energy Agency (IEA), which shows a clear lead of US in investment in renewable power.

A close look at Table 3b also shows that the coefficients of determination (R^2) are just 31%/26% for NA and 19% for EU, supporting the idea that GMP is capturing a market phenomenon manifested in the form of transition risk, which was not completely reflected by factor exposures commonly driving returns. Note that similar results are documented in the literature. For instance, Gimeno and Gonzalez (2022) report R^2 for the cross-sectional green-minus-polluting factor ranging from 0.06 to 0.34. In addition, the GMP factor is negatively related to the market factor underlying its statistical hedging properties. This is the case for the low-carbon EU- and the NA-GMPs. Interestingly, the small-minus-big (SMB) factor has a negative and significant effect on the GMP for NA but a positive effect for the European corporations when the low-carbon power companies are used. This indicates that the green factor is associated with larger firms in North America than in Europe. When the zero emitters are used, the size factor has a positive effect for the two geographical areas suggesting that it is mainly driven by lower sized corporations. The negative sign of the high-minus-low (HML) book-to-market factor across all estimations suggests that the green factor is associated with growth stocks, while the positive sign of the MOM suggests that the performance of green-versus-brown investments is largely driven by momentum. These results therefore indicate that green firms often have high valuations and are expected to achieve rapid earnings growth. Returns on green investments also lead to positive stock momentum. This is consistent with the predictions of Magnani et al. [31] which show that increased reliance in green investments leads to positive momentum and lower capital cost.

In sum, the analysis above confirms the strong performance of GMP portfolios generating economically and statistically significant factor-adjusted returns. The attractive performance is found to be stronger in the NA region. Using the proxy of GMP to measure carbon transition risk, reported results imply that regulatory framework in North America is more market driven and therefore captures the relevance of climate issues in investment decisions, rewarding renewables and low-polluting power companies with higher returns relative to their counterparts in Europe.

We next analyze the ability of GMP in generating alpha for the period 2021–2023 in Table 3c. Consistent with the summary statistics of GMP returns in the previous subsection, the US-GMP generates significant but negative abnormal returns, the alphas of which are equal to around 14 % for both low-carbon and zero-emitting GMP measurements. This implies the superior performance of brown versus green firms, reflecting investors outweighing fossil fuel companies in the aftermath of the COVID-19 shock.

This evidence highlights that the green transition is a prolonged and challenging process, often hindered by external factors such as policy uncertainty around government carbon reduction initiatives and shifting investor preferences between brown and green assets. These dynamics can significantly disrupt the pace of green transition. For the EU-GMP over the same period, the estimated alphas are statistically insignificant, indicating no clear outperformance of green or brown firms. While the EU-GMP has also declined, the downturn has been relatively moderate—largely due to the EU's ambitious sustainability agenda, especially in response to the COVID-19 crisis and the geopolitical shock of the Russian–Ukrainian war.

[14] Europe introduced the EU ETS: Emission Trading System launched in 2005.

[15] Document available at https://www.esm.europa.eu/blog/climate-change-and-industrial-transformation-different-approaches-europe-and-united-states?utm_source=chatgpt.com.

4.4. Stock return cross-section regressions

In the section we examine the ability of carbon transition risk to explain the cross-sectional variation in stock returns, using the Fama–MacBeth [32] regressions of the one-month-ahead stock returns on the carbon beta, together with a host of control variables:

$$r_{i,t+1} = \alpha + \gamma_{GMP}\widehat{\beta_{GMP}}_{i,t} + \lambda X_{i,t} + \varepsilon_{i,t+1} \tag{2}$$

where $r_{i,t+1}$ is the excess return of stock i in month $t+1$; $\widehat{\beta_{GMP}}_{i,t}$ is the estimated carbon beta at the end of month t; $X_{i,t}$ is a vector of control variables including the firm i's CAPM beta, the natural logarithm of firm i's market capitalization, and the book-to-market ratio, all of which are on a monthly basis. The descriptive statistics of firm characteristics data are provided in Table A3 in the appendix.

In this cross-sectional analysis, we focus on the constituents of the energy and utilities sectors in NA and EU. The constituents of four indexes are analyzed for this purpose (Factset code and the number of constituents in parenthesis): (a) S&P 500 Energy (SPN01-SPX, 23) and S&P Composite 1500 Utilities (SP823, 57), which represents the energy and utilities sectors in North America respectively; (b) Europe Energy & Minerals (FS2100R3,72) and Europe Utilities (FS4700R3,96), which represent the corresponding European energy and utilities sectors. All prices of these index components are in dollars and all indexes considered are exchange traded. The data source is FactSet.

Table 4a presents the time-series averages of the slope coefficients for the carbon beta and the control variables over the whole sample period 2014–2023. Our interest lies on the estimated coefficients (γ_{GMP}) for the carbon beta, which are significantly negative for the energy sector in both regions, but significantly positive for the utilities sector in NA but not for the European region. This suggests that stocks with a lower carbon transition risk (those firms in the utilities sector) deliver

Table 4a
Fama-MacBeth cross-section regressions for monthly stock returns (2014–2023).

Panel A: Energy companies				
	NA	t-stats	EU	t-stats
Constant	0.056	0.55	−0.183	−0.76
$\widehat{\beta_{GMP}}$	−0.046**	−2.46	−0.033*	−1.84
MarketBeta	0.016	0.02	0.052*	1.74
LogSize	−0.008**	−2.12	0.008	0.59
LogBM	0.012*	1.71	0.005	0.27
Adj. R^2	0.40		0.21	
Pabel B: Utilities companies				
	NA	t-stats	EU	t-stats
Constant	0.099**	2.28	0.150**	2.54
$\widehat{\beta_{GMP}}$	0.033*	1.83	0.013	1.36
MarketBeta	−0.009	−0.73	0.000	−0.22
LogSize	−0.004	−1.38	−0.010***	−2.71
LogBM	−0.005	−1.16	0.000	−0.26
Adj. R^2	0.36		0.28	

This table reports the results of Fama-MacBeth regressions of one-month-ahead stock returns on the carbon beta $\widehat{\beta_{GMP}}$, controlling for other variables, including MarketBeta, LogSize, and LogBM. In each panel, the results include the time-series averages of the slope coefficients and their Newey and West [25] adjusted *t-statistics*. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

positive one-month-ahead returns relative to those with a higher transition risk. In specific, the estimated coefficients are −0.046 and 0.033 for the energy and utilities sectors in NA, respectively. For Europe, the estimated coefficients are −0.033 and 0.013 for the energy and utilities sectors, respectively. The coefficient for the utilities sector in Europe is not statistically significant. The estimates in absolute values are greater for the NA compared to those for Europe. These material differentials unveil a greater sensitivity of stock returns to the transition risk in NA than those in Europe over the sample period considered. Moreover, the estimates for the energy sector are higher in both regions, indicating the penalty to the energy sector is more serious than the reward to the utilities sector. This is consistent with the work of Campos and Hendry [33] which shows that in the path towards the net-zero goals oil and gas corporations have a higher exposure to common global shocks.

The cross-section regressions show that the significance of carbon beta is not eroded by the inclusion of control variables. We find that only a few control variables have a significant effect on future stock returns. These are the market beta and size for EU and the size and book-to-market ratio for NA.[16] The size factor with a negative loading is the common variable in both regions, suggesting that while size effect is important in both energy and utilities sectors, it doesn't weaken the connection between firms' carbon exposure and their stock returns.

We next look at the Fama–MacBeth regression results for the period 2014–2020 presented in Table 4b.[17] All the results are consistent with those reported from the whole sample. The estimated loadings for the carbon beta are all significant with a negative sign for the energy sector and a positive sign for the utilities sector in both regions. The control variables also have a similar effect to that reported for the whole sample period in the cross-sectional analysis.

Overall, this cross-sectional evidence, in line with the GMP portfolio analysis, unveils the fact that stocks with less exposure to transition risk are preferred by investors leading to positive returns at both the portfolio and firm levels. This implies a positive stock market reaction to a firm's active engagement in carbon risk mitigation.

Table 4b
Fama-MacBeth cross-section regressions for monthly stock returns (2014–2020).

Panel A: Energy companies	NA	t-stats	EU	t-stats
Constant	0.089	0.66	−0.089	−0.48
$\widehat{\beta_{GMP}}$	−0.021*	−1.78	−0.019**	−2.05
MarketBeta	0.018	1.57	0.028*	1.93
LogSize	−0.013**	−2.45	0.005	0.48
LogBM	0.019*	1.81	−0.006	−0.60
Adj. R^2	0.12		0.13	
Pabel B: Utilities companies	**NA**	**t-stats**	**EU**	**t-stats**
Constant	0.142**	2.53	0.267**	2.46
$\widehat{\beta_{GMP}}$	0.018***	3.78	0.006*	1.91
MarketBeta	−0.016	−0.89	0.006	0.44
LogSize	−0.006**	−1.79	−0.017**	−2.46
LogBM	−0.004	−0.72	−0.001	−0.17
Adj. R^2	0.12		0.16	

This table reports the results of Fama-MacBeth regressions of one-month-ahead stock returns on the carbon beta $\widehat{\beta_{GMP}}$, controlling for other variables, including MarketBeta, LogSize, and LogBM. In each panel, the results include the time-series averages of the slope coefficients and their Newey and West [25] adjusted *t-statistics*. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

5. Measuring the carbon transition risk using GMP

5.1. GMP as A common risk exposure

In this paper, we incorporate GMP as a new risk exposure, into the traditional asset pricing framework with the three factors of Fama-French (1993) and the momentum factor of Carhart [30]. This extended model is presented as follows:

$$r_{p,t} - r_f = \alpha + \beta_1 \left(R_{M,t} - r_f\right) + \beta_2 SMB_t + \beta_3 HML_t + \beta_4 MOM_t + \beta_{GMP} GMP_t + v_t \quad (3)$$

$$\beta_4 MOM_t + \beta_{GMP} GMP_t + v_t \quad --Delete \tag{3}$$

where $r_{p,t} - r_f$ is the excess return of a portfolio p over the risk-free interest rate on day t. Portfolio returns are explained by the excess return in the market $R_{M,t}$ over the risk-free return r_f, as well as by the size factor SMB_t (small minus big), the value factor HML_t (high minus low), the momentum factor MOM_t (winners minus losers), and the GMP_t that refers to the time-series value of the GMP portfolio, respectively. The objective is to reveal whether GMP is able to capture the carbon transition risk which is pronounced for industries involved in the energy sector which are hard-to-abate. The significance and sign of β_{GMP} thus uncovers the existence of carbon premium.

As a preliminary analysis, we look at the correlation relationship between GMP and the other common risk factors. Reported results in Table 5 show that the highest correlation is observed for the value and momentum factors. GMP exhibits the positive and highest correlation with the momentum factor in NA suggesting that the strong performance of green stocks is possibly associated with the positive performance of momentum. In addition, the negative correlation between GMP and the value factor (which is particularly strong in the EU GMP factor) is consistent with Pastor et al. (2022) which reflects the fact that value stocks are more often brown than green.

Table 5
Correlation matrix between GMP based on low-carbon power companies and common risk factors (2014–2023).

North America	GMP	Mkt-RF	SMB	HML	MOM
GMP	1.00				
Mkt-RF	−0.28***	1.00			
SMB	−0.22***	0.20***	1.00		
HML	−0.38***	−0.05***	−0.02	1.00	
MOM	0.27***	−0.15***	−0.20***	−0.32***	1.00
Europe	**GMP**	**Mkt-RF**	**SMB**	**HML**	**MOM**
GMP	1.00				
Mkt-RF	−0.20***	1.00			
SMB	0.17***	−0.41***	1.00		
HML	−0.44***	0.14***	−0.20***	1.00	
MOM	0.17***	−0.26***	0.12***	−0.35***	1.00

The common risk factors considered include Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long for low-carbon power companies and short for polluting oil and gas companies. *, ** and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

[16] Note that book-to-market is only significant for NA and market beta is only for EU.

[17] We only report the Fama–MacBeth regression results for the first subsample period 2014–2020, while the results for the second subsample period 2021–2023 are not reported. The reason is that the observations are limited for regression analysis considering the short time-span of 2021–2023 under the use of quarterly firm-level data.

5.2. The explanatory power of GMP

We now proceed to analyze the explanatory power of GMP for both energy and utilities sectors in NA and EU. The sample firms are the same as used in Section 4.4. With the components considered, we construct two equal-weighted portfolios (energy and utilities portfolios) for each geographical area.[18] The daily (log) returns of these portfolios are then regressed against the Fama-French (1993) three factors, the momentum factor of Carhart [30] and the newly proposed GMP, as is specified in Equation (3). We seek to examine whether GMP has the capacity to explain the equity performance of the constituents of the energy and utilities sectors. We report these regression results for the whole sample period 2014–2023 in Tables 6–9. Results for the two subsamples covering the periods 2014–2020 and 2021–2023 are reported in tables A4-1 to A4-4 and tables A5-1 to A5-4 in the appendix.[19]

5.2.1. The case of energy portfolios in NA and EU

Empirical results for energy portfolios are reported in Table 6. Panel A demonstrates that GMP has a significant and negative impact on the portfolio return of energy corporates in NA. This suggests that investors punish companies in the energy sector due to their exposure to transition risk and increased climate awareness. This is not consistent with Bolton and Kaeprezyk (2021) who documented carbon premium for stocks exposed to transition risk. Investors are therefore more inclined to invest in green stocks. The explanatory power of GMP is also reflected in the change of factor loadings present in columns 1 and 2. The inclusion of GMP leads to a lower loading on the market risk, the value, size, and momentum effects, the decrease of which is higher than 20 %. This result implies that the exposure to transition risk is no longer a dormant risk nowadays since the returns of the energy portfolio not captured by the conventional measures of systematic risk are explained by GMP. In addition, the measurement of transition risk through GMP also leads to an increase in the adjusted R^2, which raises from 0.60 to 0.84.

We then examine to what extent the strong performance of green stocks relative to their polluting counterparts accounts for the performance of the EU energy portfolio. Panel B of Table 6 reports the estimated factor loadings. As expected, regression results demonstrate a significant and negative effect of GMP on the European energy portfolio. However, the impact on portfolio returns is much lower than that

Table 6
The explanatory power of GMP (based on low-carbon power companies) on energy portfolios (2014–2023).

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
Alpha	−0.008	−0.015	0.019	0.015
	(-0.24)	(-0.73)	(0.89)	(0.78)
Mkt-RF	1.194***	0.886***	0.917***	0.844***
	(41.60)	(46.88)	(39.46)	(41.19)
SMB	0.611***	0.266***	0.234***	0.286***
	(11.82)	(7.99)	(4.05)	(5.65)
HML	1.249***	0.667***	1.049***	0.601***
	(32.69)	(25.57)	(24.76)	(14.86)
MOM	−0.254***	−0.141***	0.056*	0.040
	(-7.99)	(-6.99)	(1.73)	(1.42)
GMP		−0.638***		−0.412***
		(-60.15)		(-27.43)
Adj. R^2	0.60	0.84	0.53	0.64

Regression of the returns of energy portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

Table 7
The explanatory power of GMP (based on zero-emitters) on energy portfolios (2014–2023).

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
Alpha	−0.008	−0.006	0.019	0.032
	(-0.24)	(-0.26)	(0.89)	(1.61)
Mkt-RF	1.194***	0.981***	0.917***	0.920***
	(41.60)	(44.21)	(39.46)	(43.98)
SMB	0.611***	0.672***	0.234***	0.481***
	(11.82)	(17.25)	(4.05)	(9.06)
HML	1.249***	0.723***	1.049***	0.691***
	(32.69)	(23.09)	(24.76)	(16.87)
MOM	−0.254***	−0.163***	0.056*	0.109***
	(-7.99)	(-6.80)	(1.73)	(3.72)
GMP		−0.518***		−0.364***
		(-43.01)		(-23.92)
Adj. R^2	0.60	0.77	0.53	0.62

Regression of the returns of energy portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on renewable energy companies regarded as zero carbon-emitters and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

Table 8
The explanatory power of GMP (based on low-carbon power companies) on utilities portfolios (2014–2023).

	Panel A		Panel B	
	NA utilities portfolio		EU utilities portfolio	
Alpha	−0.010	−0.008	−0.005	−0.004
	(-0.76)	(-0.72)	(-0.53)	(-0.45)
Mkt-RF	0.352***	0.430***	0.382***	0.397***
	(30.94)	(41.70)	(36.24)	(38.20)
SMB	−0.072***	0.015	0.095***	0.084***
	(-3.51)	(0.82)	(3.61)	(3.29)
HML	0.138***	0.284***	−0.044**	0.046**
	(9.10)	(20.00)	(-2.27)	(2.25)
MOM	−0.011	−0.039***	−0.030**	−0.027*
	(-0.86)	(-3.55)	(-2.06)	(-1.88)
GMP		0.160***		0.083***
		(27.76)		(10.86)
Adj. R^2	0.30	0.47	0.39	0.42

Regression of the returns of utilities portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

[18] Note that we use an equally weighted measure to avoid the overweight to green stocks that arises if we weight by market cap as green stocks trade with higher market cap than brown stocks (for instance, Ref. [2]).

[19] The results obtained from the two subsamples are consistent with those from the whole sample, which accordingly serve as the robustness supporting the significant explanatory power of GMP.

Table 9
The explanatory power of GMP (based on zero-emitters) on utility portfolios (2014–2023).

	Panel A		Panel B	
	NA utilities portfolio		EU utilities portfolio	
Alpha	−0.010	−0.010	−0.005	−0.007
	(-0.76)	(-0.82)	(-0.53)	(-0.71)
Mkt-RF	0.352***	0.389***	0.382***	0.382***
	(30.94)	(34.79)	(36.24)	(36.52)
SMB	−0.072***	−0.083***	0.095***	0.061**
	(-3.51)	(-4.20)	(3.61)	(2.30)
HML	0.138***	0.229***	−0.044**	0.005
	(9.10)	(14.54)	(-2.27)	(0.26)
MOM	−0.011	−0.027**	−0.030**	−0.038**
	(-0.86)	(-2.19)	(-2.06)	(-2.56)
GMP		0.090***		0.050***
		(14.82)		(6.54)
Adj. R^2	0.30	0.36	0.39	0.40

Regression of the returns of utilities portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on renewable energy companies regarded as zero-carbon emitters and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

reported for the NA energy portfolio. This can be seen in the magnitude of the coefficient of GMP and the adjusted R^2. In specific, the estimate of GMP in column 4 is −0.41, which is 0.23 points lower in absolute value than that reported for the NA equal to −0.64. This implies that as green stocks deliver a higher profitability in NA (compared to those in EU), the polluting firms belonging to the energy sector experience a more substantial decline in the equity market. This is also consistent with the view that transition risk is greater in the NA market, for instance, the work of Pickl [24] which suggests that the US oil and gas majors are lagging in green investment. The increase in the goodness of fit arising from the inclusion of GMP is also notably larger for the NA (adjusted $R^2 = 0.84$) compared to the EU (adjusted $R^2 = 0.64$). This is consistent with our finding that GMP generally outperforms in NA when compared to the EU, the greater explanatory power in NA suggests a higher transition risk in this area which drives investors' divestment of polluting assets.

As a means of robustness, we use the GMP based on zero-emitters as an alternative measure of transition risk. Results reported in Table 7 show the same effects of GMP on explaining the performance of energy corporates in both NA and EU areas.

The low-carbon transition requires a greater reliance on green production technologies which may reduce expected returns on energy corporates because of the substantial cost of technology upgrading and technical uncertainties. Given this, we find that the GMP portfolio which captures carbon transition risk can explain the evolution of stock prices of energy corporations. Its explanatory power is stronger in NA than EU, indicating that carbon transition risk is stronger in NA than in the EU. Such finding can be explained by the fact that US oil majors have historically invested less in renewables compared to their European counterparts. This exposes them to transition risk as global demand shifts toward low-carbon energy.

5.2.2. *The case of utilities portfolios in NA and EU*

Results from analyzing the impact of GMP on the utilities portfolios are reported in Table 8. We see that GMP has a significantly positive effect on returns on the utilities sector in both geographical areas considered. This indicates a reward to the constituents of this sector that are known to invest in the green transition. The magnitude of the coefficient on GMP is 0.16 and 0.08 for NA and EU respectively, which suggests that the explanatory power of GMP in NA is almost two times greater than that in EU. This may be related to the lower profitability delivered by the European GMP based on the low-carbon power companies, as reported in Table 2. In addition, the inclusion of GMP significantly enhances the goodness of fit of the regression as observed for the NA utilities portfolio, which increases from 0.30 to 0.47. However, GMP does not add much power to explain the EU utilities portfolio as the adjusted R^2 keeps stable (around 0.40) after controlling for GMP in the model.

The greater loading on the GMP factor and the improved explanatory power of the model that includes it indicate that GMP plays a more influential role in the North American region during the 2014–2023 period. This suggests that investors in this market are increasingly incorporating carbon performance into their investment decisions.

A comparison of the estimates in Tables 6 and 8 shows that the coefficients on GMP in absolute value are notably higher for energy portfolios than for utilities portfolios. In other words, the return penalization for the energy sector is much greater than the reward obtained by corporates in the utilities sector. This finding suggests that the increase in climate change awareness in the last decade triggers mainly changes in investors' perceptions on high-polluting energy companies. Divesting from fossil fuel assets could be a possible attribution to this evidence under the prevailing trend of sustainable investing.

Table 9 reports the regression results for the utilities portfolios after controlling for GMP built with renewable energy companies that are zero-carbon emitters. We find a greater estimated coefficient of GMP in NA than EU (0.09 vs. 0.05), which is consistent with the results reported in Table 8. We note another interesting finding in the size effect. The estimates of SMB factor exhibit opposite sign for the two regions, whose value is negative for the NA but positive for the EU. This indicates utilities companies in NA are in general larger firms while those in EU are smaller in size. This is aligned with the finding of Gimeno and Gonzalez (2022) reporting differences in SMB for the U.S.and EU. Comparing the magnitudes of SMB in both regions suggests that size effect is more pronounced in the NA utilities sector.

A comparison between Tables 8 and 9 reveals that the alternative GMP factor has a weaker impact on the returns of utilities portfolios in both regions, as reflected by the lower estimated GMP coefficients. Additionally, the factor contributes only marginally to the explanatory power, with adjusted R^2 increasing modestly from 0.30 to 0.36 for North America and from 0.39 to 0.40 for Europe. This suggests that the renewable energy sector may not be closely aligned with the utilities sector, possibly due to differences in their business models and distinct transition pathways toward carbon neutrality.

The findings reported in this section are consistent with those reported in Tables 6 and 7, suggesting that the GMP factor is more powerful in explaining the returns of utilities sector for NA than in the EU region. Such positive effect of GMP support our previous findings suggesting that green companies are rewarded by the financial market given the increased climate change awareness in the past decade.

6. Discussion and conclusions

Energy corporates are heavily exposed to carbon-transition risk as the global economy fights to transform from fossil fuels to green energy. Measuring the impact of carbon transition risk is crucial to make investment decisions.

This study advances the carbon risk pricing literature by proposing a new market-based metric—the GMP factor—to capture transition risk using only equity data from energy-related firms. By employing an emissions intensity metric grounded in the Greenhouse Gas Protocol and aligned with the methodology of the Transition Pathway Initiative, this study offers a sector-specific approach to standardize carbon emissions. Focusing on emissions per unit of energy produced provides a more accurate and meaningful assessment of carbon performance in the oil and gas and power utilities sectors, where energy production is the core business activity. Unlike broader approaches that scale emissions by firm sales or market capitalization (see Ref. [26,34]), our method better captures the direct relationship between operational output and carbon emissions. This enables more consistent benchmarking across firms and enhances the relevance of carbon intensity as a tool for investors and stakeholders tracking climate transition risks in high-emitting sectors.

Therefore, the proposed emissions intensity measure improves on existing benchmarks (e.g., Refs. [4,5]; Pastor et al., 2022) by standardizing carbon intensity using consistent, activity-based metrics. This enables a more accurate and comparable evaluation of transition risk across energy firms with varying business models and technologies.

High-emitting companies are identified from the oil and gas companies in the energy sector, while low-emitting ones are selected from the low-carbon power companies in the utilities sector and alternatively from renewable energy producers that are viewed as zero-carbon emitters. We build the GMP portfolios for both North America and Europe areas, for the purpose to discover the different paces of low-carbon economy development. Our framework aligns with Acharya et al. [17], who focus their analysis on the energy sector. They distinguish between adaptive new entrants—represented in our study by low or zero-emission utilities—and incumbent firms already invested in carbon-intensive energy production, corresponding to the oil and gas companies of the proposed setup.

Our analysis reveals a structural break in the GMP factor over the sample period, coinciding with the key macro event such as the post-COVID recovery. This structural shift prompts a split analysis, namely 2014–2020 and 2021–2023. Between 2014 and 2020, North American GMP portfolios show strong abnormal returns (9–10%), which turn negative in the 2021–2023 period. In Europe, zero-emission portfolios yield 6 % abnormal returns initially but show no significant profitability afterward. The finding of improved performance in the NA over the first sample period suggests that the NA region's market-driven regulatory environment more effectively prices carbon transition risk, rewarding cleaner energy companies with higher returns compared to Europe. However, the documented structural break delivers changing pattern of abnormal returns, highlighting a significant evolution in how financial markets price transition risk. This is consistent with Parker and Engle [16], who document notably time changing characteristics in the proposed hedged portfolios which deliver lower profitability after 2020.

Our results further highlight that focusing specifically on the energy sector uncovers idiosyncratic differences between Europe and North America. This supports the evidence provided by Bauer et al. [10] which considers corporations in the G7 and finds green outperformance in the US sample. However, it contrasts with prior studies examining broader cross-sections of firms across multiple sectors, which have found that average market performance in the U.S. and EU tends to be closely aligned [23]. Reported results suggest that, despite differing regulatory frameworks in the two regions (see Table A1 in the Appendix), the COVID-19 pandemic contributes to a convergence in performance between European and North American markets during the period analyzed.

Reported results contribute to the growing literature on the existence of a "greenium" in equity markets by showing that its behavior has shifted over the past five years. This shift appears to be influenced by the tightening of green regulatory requirements and heightened geopolitical tensions—most notably the energy crisis and the war in Ukraine—which have significantly affected how markets price sustainability-related risks and opportunities.

The existence of greenium reflects investors' preference for green companies with lower carbon intensity. Carbon transition is not only perceived as a long-term risk in nature, but is also already priced in the equity value. Our results corroborate the view that investments in low-carbon technologies provide a hedge against climate change risk [35]. This evidence is relevant for investors and fund managers who need to incorporate the effect of transition risks in their investment decisions and for energy companies that aim to improve their corporate performance in the low-carbon transition process.

CRediT author statement

Isabel Figuerola-Ferretti: Conceptualization, Methodology, Investigation, Writing-Original draft preparation, Supervision, Writing-Reviewing and Editing, **F. Javier Sanz:** Conceptualization, Methodology, Data curation, Writing-Original draft preparation, Writing-Reviewing and Editing, **Tao Tang**: Formal analysis, Methodology, Software, Investigation, Writing-Original draft preparation, Writing-Reviewing and Editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1
EU vs U.S. Sustainable Finance and Climate Regulations

Year	European Union	United States
2005	Introduction of European ETS **carbon pricing system**	**Energy Policy Act**: infrastructure & innovation support
2015	**Paris Agreement** The world committed to the 1.5 Celsius objective	**Paris Agreement** The world committed to the 1.5 Celsius objective
2018	**EU Action Plan on Sustainable Finance** unveiled, setting the framework to integrate sustainability into the financial system.	The **U.S.** has no single comprehensive sustainable finance plan but focuses on **ESG disclosures** through regulatory frameworks such as the **SEC's climate-related disclosures** proposal (2021).
2019	**European Green Deal** introduced, aiming for carbon neutrality by 2050	**U.S. Green New Deal** proposals introduced, but not passed at the federal level
2020	**EU Taxonomy Regulation** introduced to classify sustainable economic activities.	The **U.S. SEC** began exploring climate disclosure requirements for companies, with the **SEC** proposing climate-related disclosure rules in 2021.
2021	**Sustainable Finance Disclosure Regulation (SFDR)** enacted, requiring financial market participants to disclose how sustainability risks are integrated into investment strategies.	**Bipartisan Infrastructure Law** (2021) included provisions for clean energy, electric vehicle infrastructure, and grid improvements.
2021	**Fit for 55** package introduced, targeting a 55 % emissions reduction by 2030 and supporting investments in clean technologies.	**U.S.** saw the passage of the **Infrastructure Investment and Jobs Act (IIJA)** in 2021, which allocated funds for clean energy technologies, climate resilience, and infrastructure projects.

(*continued on next page*)

Table A1 (*continued*)

Year	European Union	United States
2022	**Green Deal Industrial Plan** proposed, aimed at boosting renewable energy and reducing reliance on fossil fuels like Russian gas.	The **U.S. Inflation Reduction Act (IRA)** focuses on tax credits and incentives for clean energy, carbon capture, and energy efficiency, providing tax credits for clean energy investments.
2050	EU aims to achieve **climate neutrality** with sustainable finance mechanisms playing a central role.	**U.S.** sets **net-zero by 2050** as an aspirational goal, supported by policies like the **IRA**, but lacks comprehensive federal laws directly aimed at sustainability in finance.

Table A2
Descriptive statistics of common risk factors

	Num	Mean	Median	Stdev	Max	Min	Sharpe
Panel A: the U.S. factors							
Mkt-RF	2433	12.17 (2.10)**	20.16	18.01	9.34	−12.00	0.68
SMB	2433	0.62 (0.19)	0.00	10.09	5.54	−3.60	0.06
HML	2433	−1.70 (-0.38)	−10.08	13.96	6.74	−5.02	−0.12
MOM	2433	−1.15 (-0.21)	12.60	17.24	5.93	−14.37	−0.07
Panel B: the European factors							
Mkt-RF	2433	6.05 (1.12)	15.12	16.85	8.54	−12.01	0.36
SMB	2433	−0.05 (-0.02)	0.00	6.67	1.94	−3.29	−0.01
HML	2433	−1.39 (-0.49)	−7.56	8.89	4.38	−3.03	−0.16
MOM	2433	7.19 (1.90)*	15.12	11.73	4.56	−10.87	0.61

This table reports the (annualized) mean return, the (annualized) standard deviation, skew, kurtosis, the maximum and minimum daily return, and the (annualized) Sharpe ratios for those common risk factors in the North American and European markets. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

Table A3 Descriptive statistics of firm characteristics

	Num	Mean	Median	Stdev	Max	Min
Panel A: NA energy companies						
$\widehat{\beta_{GMP}}$	1599	−0.89	−0.86	0.29	−0.42	−1.72
MarketBeta	1599	0.26	−0.16	0.97	4.19	−2.24
LogSize	1599	15.26	15.83	4.01	19.88	10.60
LogBM	1599	2.16	3.12	1.45	4.59	0.68
Panel B: NA utilities companies						
$\widehat{\beta_{GMP}}$	1645	0.10	0.09	0.06	0.24	−0.01
MarketBeta	1645	0.30	0.21	0.37	2.72	−0.44
LogSize	1645	15.45	16.07	4.17	18.72	12.66
LogBM	1645	2.22	3.15	1.37	4.11	1.32
Panel C: EU energy companies						
$\widehat{\beta_{GMP}}$	1152	−0.63	−0.60	0.29	−0.20	−1.21
MarketBeta	1152	0.50	0.63	0.70	4.22	−2.08
LogSize	1152	12.76	15.93	6.32	19.48	7.43
LogBM	1152	1.47	1.93	1.21	2.68	0.24
Panel D: EU utilities companies						
$\widehat{\beta_{GMP}}$	2479	0.16	0.10	0.16	0.55	−0.07
MarketBeta	2479	0.61	0.65	0.60	4.45	−1.75
LogSize	2479	11.49	14.25	5.95	19.00	5.04
LogBM	2479	1.50	1.00	1.03	3.29	0.21

This table reports the summary statistics of firm characteristics including carbon beta $\widehat{\beta_{GMP}}$, MarketBeta, LogSize, and LogBM, for energy and utilities companies in both NA and EU. The sample period is 2014–2023. Source: Authors' calculations based on Factset data.

Table A4-1
The explanatory power of GMP (based on low-carbon power companies) on energy portfolios (2014–2020)

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
Alpha	−0.062*	−0.028	0.002	−0.002
	(-1.90)	(-1.19)	(0.1)	(-0.10)
Mkt-RF	1.269***	0.973***	1.047***	0.979***
	(43.6)	(43.53)	(40.37)	(41.09)
SMB	0.517***	0.275***	0.346***	0.425***
	(9.05)	(6.60)	(5.87)	(7.49)
HML	0.479***	0.403***	0.693***	0.424***
	(8.32)	(9.67)	(11.82)	(7.69)
MOM	−0.928***	−0.461***	−0.137***	−0.073**
	(-21.01)	(-13.54)	(-3.46)	(-2.01)
GMP		−0.542***		−0.338***
		(-39.42)		(-18.98)
Adj. R^2	0.71	0.85	0.63	0.70

Regression of the returns of energy portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

Table A4-2
The explanatory power of GMP (based on zero-emitters) on energy portfolios (2014–2020)

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
Alpha	−0.062*	−0.028	0.002	0.013
	(-1.90)	(-0.95)	(0.1)	(0.61)
Mkt-RF	1.269***	1.143***	1.047***	1.084***
	(43.6)	(42.21)	(40.37)	(45.25)
SMB	0.517***	0.576***	0.346***	0.569***
	(9.05)	(11.15)	(5.87)	(10.20)
HML	0.479***	0.409***	0.693***	0.504***
	(8.32)	(7.84)	(11.82)	(9.16)
MOM	−0.928***	−0.681***	−0.137***	−0.015
	(-21.01)	(-16.27)	(-3.46)	(-0.41)
GMP		−0.346***		−0.275***
		(-19.63)		(-17.47)
Adj. R^2	0.71	0.85	0.63	0.69

Regression of the returns of energy portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on renewable energy companies regarded as zero carbon-emitters and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

Table A4-3
The explanatory power of GMP (based on low-carbon power companies) on utilities portfolios (2014–2020)

	Panel A		Panel B	
	NA utilities portfolio		EU utilities portfolio	
Alpha	−0.005	−0.014	−0.004	−0.003
	(-0.5)	(-1.54)	(-0.58)	(-0.54)
Mkt-RF	0.289***	0.362***	0.371***	0.375***
	(30.87)	(42.97)	(50.40)	(50.69)
SMB	−0.058***	0.001	0.164***	0.159***
	(-3.18)	(0.08)	(9.76)	(9.57)
HML	0.159***	0.177***	0.102***	0.120***
	(8.58)	(11.30)	(6.11)	(7.00)
MOM	0.054***	−0.062***	0.056***	0.052***
	(3.79)	(-4.79)	(5.01)	(4.62)
GMP		0.134***		0.023***
		(25.81)		(4.17)
Adj. R^2	0.40	0.57	0.65	0.66

Regression of the returns of utilities portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

Table A4-4
The explanatory power of GMP (based on zero-emitters) on utility portfolios (2014–2020)

	Panel A		Panel B	
	NA utilities portfolio		EU utilities portfolio	
Alpha	−0.005	−0.011	−0.004	−0.004
	(-0.5)	(-1.09)	(-0.58)	(-0.68)
Mkt-RF	0.289***	0.3107***	0.371***	0.367***
	(30.87)	(33.14)	(50.40)	(50.03)
SMB	−0.058***	−0.069***	0.164***	0.151***
	(-3.18)	(-3.83)	(9.76)	(8.79)
HML	0.159***	0.171***	0.102***	0.112***
	(8.58)	(9.46)	(6.11)	(6.64)
MOM	0.054***	0.011	0.056***	0.050***
	(3.79)	(0.76)	(5.01)	(4.32)
GMP		0.060***		0.016***
		(9.78)		(3.26)
Adj. R^2	0.40	0.43	0.65	0.69

Regression of the returns of utilities portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on renewable energy companies regarded as zero-carbon emitters and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2014–2020. Source: Authors' calculations based on Factset data.

Table A5-1
The explanatory power of GMP (based on low-carbon power companies) on energy portfolios (2021–2023)

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
Alpha	0.060	−0.029	0.038	0.035
	(0.93)	(-0.84)	(0.76)	(0.84)
Mkt-RF	1.215***	0.832***	0.771***	0.681***
	(19.07)	(23.31)	(16.41)	(17.35)
SMB	0.620***	0.235***	0.320**	0.183
	(6.67)	(4.59)	(2.24)	(1.54)
HML	1.296***	0.616***	1.144***	0.574***
	(19.54)	(15.63)	(14.71)	(8.00)
MOM	0.237***	−0.005	0.177**	0.004
	(4.08)	(-0.16)	(2.51)	(0.08)
GMP		−0.713***		−0.501***
		(-41.73)		(-18.16)
Adj. R^2	0.50	0.85	0.37	0.57

Regression of the returns of energy portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2021–2023. Source: Authors' calculations based on Factset data.

Table A5-2
The explanatory power of GMP (based on zero-emitters) on energy portfolios (2021–2023)

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
Alpha	0.060	−0.030	0.038	0.049
	(0.93)	(-0.72)	(0.76)	(1.21)
Mkt-RF	1.215***	0.862***	0.771***	0.612***
	(19.07)	(20.36)	(16.41)	(15.72)
SMB	0.620***	0.846***	0.320**	0.367***
	(6.67)	(14.07)	(2.24)	(3.17)

(*continued on next page*)

Table A5-2 (*continued*)

	Panel A		Panel B	
	NA energy portfolio		EU energy portfolio	
HML	1.296***	0.564***	1.144***	0.416***
	(19.54)	(11.68)	(14.71)	(5.68)
MOM	0.237***	0.065*	0.177**	0.054
	(4.08)	(1.73)	(2.51)	(0.93)
GMP		−0.636***		−0.512***
		(-32.14)		(-19.45)
Adj. R^2	0.50	0.79	0.37	0.59

Regression of the returns of energy portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on renewable energy companies regarded as zero carbon-emitters and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2021–2023. Source: Authors' calculations based on Factset data.

Table A5-3
The explanatory power of GMP (based on low-carbon power companies) on utilities portfolios (2021–2023)

	Panel A		Panel B	
	NA utilities portfolio		EU utilities portfolio	
Alpha	−0.023	0.004	−0.009	−0.008
	(-0.71)	(0.14)	(-0.30)	(-0.28)
Mkt-RF	0.542***	0.658***	0.385***	0.411***
	(16.83)	(22.77)	(13.96)	(15.41)
SMB	−0.139***	−0.023	−0.226***	−0.186**
	(-2.96)	(-0.56)	(-2.70)	(-2.31)
HML	0.304***	0.509***	−0.118***	0.049
	(9.06)	(15.95)	(-2.59)	(1.01)
MOM	−0.119***	−0.046*	−0.129***	−0.078*
	(-4.06)	(-1.79)	(-3.10)	(-1.93)
GMP		0.215***		0.147***
		(15.54)		(7.83)
Adj. R^2	0.32	0.49	0.28	0.34

Regression of the returns of utilities portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on low-carbon power companies and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2021–2023. Source: Authors' calculations based on Factset data.

Table A5-4
The explanatory power of GMP (based on zero-emitters) on utility portfolios (2021–2023)

	Panel A		Panel B	
	NA utilities portfolio		EU utilities portfolio	
Alpha	−0.023	−0.002	−0.009	−0.010
	(-0.71)	(-0.08)	(-0.30)	(-0.36)
Mkt-RF	0.542***	0.623***	0.385***	0.408***
	(16.83)	(19.89)	(13.96)	(14.61)
SMB	−0.139***	−0.191***	−0.226***	−0.233***
	(-2.96)	(-4.29)	(-2.70)	(-2.81)
HML	0.304***	0.471***	−0.118***	−0.013
	(9.06)	(13.20)	(-2.59)	(-0.24)
MOM	−0.119***	−0.080***	−0.129***	−0.111***
	(-4.06)	(-2.88)	(-3.10)	(-2.68)
GMP		0.145***		0.089***
		(9.92)		(3.93)
Adj. R^2	0.32	0.40	0.28	0.30

Regression of the returns of utilities portfolios against the common risk factors including Mkt-RF (market excess return over the risk-free return), SMB (small minus big), HML (high minus low), and MOM (winners minus losers) factors, as well as the newly proposed GMP (green-minus-polluter). The GMP is built as a portfolio going long on renewable energy companies regarded as zero-carbon emitters and short on polluting oil and gas companies. Panel A reports the regression results for North America while Panel B for Europe. The *t-statistics* based on Newey and West [25] standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The sample period is 2021–2023. Source: Authors' calculations based on Factset data.

Data availability

Data will be made available on request.

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