

RESEARCH ARTICLE

The Low-carbon Equity Market: A New Alternative for Investment Diversification?

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Funding information

CEFAGE; GECOS

Abstract

Addressing the topic of ethical investment, this paper considers stock market indices related to climate change and provides the first comprehensive analysis of the links between low-carbon equities and conventional equities. Results show that in the long run, low carbon economy indices do not behave like conventional indices, and no balance relationship is identified between the two, such that investors can find in the low-carbon sector an opportunity to diversify investment as an alternative to traditional equity investment. In the short-run, the two investment segments display identical behaviour, especially in contemporary terms, with daily dynamics driven fundamentally by market factors. These results will help regulators and policy makers to design policies for sustainable equity investment according to macroprudential policies.

1 | LOW-CARBON ALTERNATIVE INVESTMENT

Recent decades have been marked by a change in business management models in such a way that they do not simply accommodate the financial perspective, but also stakeholders diverse viewpoints. This change is embodied in several research works (e.g., Agle, 2008; Wood, 2008) that question Friedman's (1970) proposal, according to which the mission of a company is to maximize shareholder value.

Concerns about global warming and climate change, the environment, the scarcity of water, issues related to human rights and poverty, and financial crises among other factors, have helped to validate the theme of sustainability among stakeholders because, in strategic terms, it can also bring added value to the business itself (Elijido-Ten & Clarkson, 2019; KPMG, 2011; Porter

& Kramer, 2006; Vives & Wadhwa, 2012). This greater awareness also extends to the financial sector, which – like investors – includes carbon-risk exposure in its decision making (Herbohn et al. 2019; Mace et al. 2021).

Sustainable investment, also called socially responsible investment or ethical investment, is based on the idea of the triple bottom line (people, planet, profit), according to which a company's results should not be measured exclusively by the yardstick of conventional financial criteria, but should also consider non-financial criteria (Brzeszczynski & McIntosh, 2014; Renneboog et al. 2008); namely social (labour and human rights, health and safety, and community relations, among others), governance (good governance, ethical issues, accountability, bribes and corruption, among others), and environmental (biodiversity, water management, pollution, and climate change, among others) criteria. With regard to environmental objectives,

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the issue of climate change deserves special mention, and has spurred the efforts of academics, politicians, and researchers to seek a more sustainable path for the planet and for economies. The corollary of these efforts gained global expression in the Paris Agreement and the United Nations 2030 Agenda for Sustainable Development, which was launched in 2015 and defined the 17 Sustainable Development Goals (SDGs). At the same time, with the world in the throes of a pandemic, Bolton et al. (2020) understand that the health crisis caused by the COVID-19 virus and climate change have common elements, insofar as they stem from a strange combination of human action and the forces of nature, triggering contradictory feelings of guilt and lack of control. In this sense, the authors argue that the crisis has accentuated interest in sustainability and the resilience of societies and, therefore, in the role to be played by the financial sector in changing the economic paradigm to one based on sustainability. As He and Harris (2020) discuss, 'the COVID-19 pandemic offers a great opportunity for businesses to shift towards more genuine and authentic CSR and contribute to address urgent global social and environmental challenges' thereby contributing towards progress on the United Nations' SDGs.

In recent years, it has become evident that many investors are interested in considering environmental, social, and governance (ESG) criteria in their investment decisions (Clementino & Perkins, 2020), to the extent that it is possible to reconcile the financial profitability of investments with the sustainability of society (Eurosif, 2008; Statman & Glushkov, 2008). The greater sensitivity to issues related to sustainability has helped the emergence of sustainable stock market indices, which attract an increasing number of investors (Cortez et al. 2009). There is no doubt that investing in assets of a sustainable nature will help to achieve the current and relevant Sustainable Development Goals. This action will in turn attract funding for companies and will increase sustainable development at a corporate and market level, and at the same time will increase the diversification opportunities and the risk assumptions can be modified.

With the aim of identifying opportunities for diversifying investment on a global scale, various research works have studied the links between international stock markets. For this purpose, the main traditional stock market capitalizations, based on a purely financial logic, as well as various types of stock market segments, namely those which fall within the scope of so-called sustainable investment are considered. This topic of study is very important to policy makers and regulators alike because of the implications it has *vis-à-vis* the stabilization of financial markets. It is also of interest to investors, as understanding the volatility transmission process between markets is an important element in determining the respective risk premiums and asset

Policy implications

- Investors find in the low-carbon sector a real opportunity to diversify investment, as an alternative to traditional equity investment.
- Regulators should adopt adequate actions to limit down-side risk and risk of contagion across equity segments, preventing the occurrence of major crisis events.
- Financial authorities and financial markets should improve the information available to investors, minimizing asymmetric information and controlling adverse selection.
- Policy makers should design policies for sustainable equity investment in line with macro-prudential policies.

prices. In this regard, Grewal et al. (2020) argue that the prices of companies that disclose information about sustainability have greater information capacity. The information is also of interest to portfolio managers, particularly with regard to the issue of risk diversification (Miralles-Quirós & Miralles-Quirós, 2017). According to portfolio diversification theory, weak links between markets implies an increase in the international diversification alternatives, and vice-versa.

Although the study of the linkages between stock markets has received great attention from researchers and academics, conventional indices have been favoured, with only a small number of works being devoted to the linking mechanisms between sustainable indices and conventional indices. Works relating to the two stock market investment segments have, above all, sought to compare the performance of both (Bauer et al. 2007; Edmans, 2007; Marti et al. 2015; Skare & Golja, 2012).

A priori, a significant percentage of investors will be interested in safeguarding their financial interests, without compromising sustainable development, in light of the premises defined in the Paris Agreement and the 2030 Agenda. Monasterolo and De Angelis (2020) concluded that, since the Paris Agreement, stock market investors have started to consider low-carbon assets as an appealing investment opportunity, but have not yet penalized carbon-intensive assets. At a time of high sensitivity to the theme of climate change, we believe that greater knowledge of investment related to sustainable business is important. For this purpose, the differentiation factor of the stock market indices is a fundamental element, insofar as it helps to understand whether, in the face of conventional investment, the assets representing sustainable investment show the same patterns of behaviour, in both the short term and long term.

The present research expands the finance literature, in both the empirical and methodological sense, within the scope of the analysis of links between investment segments in the long run and in the short run. The great majority of existing works have tended to favour the use of traditional indices, which are dominated by large capitalizations and financial logic, without addressing environmental issues. The present work therefore fills an important empirical gap by studying the links generated in the long run and in the short run between indices that are representative of the low-carbon economy and traditional global indices, emphasizing the environmental dimension of socially responsible investment and, specifically, the impact of investment on climate change, in line with goal number 13 of the 2030 Agenda for Sustainable Development, dedicated to climate action. There is abundant literature addressing sustainability research, both from a pure corporate focus as well as from the market valuation focus. This paper seeks to integrate those studies on the corporate environment (related to the stakeholder theory) and market perspectives (related to portfolio theories and diversification).

We find no balanced relationship identified between traditional and low carbon indices in the long run, which can provide investors with a real opportunity to diversify in the low-carbon sector. In contrast, in contemporary terms, the behaviour of both investment segments is similar, which can provide financial authorities and policy makers with tools to design policy actions to better direct sustainable equity investment and risk control. Consequently, our results find similarities in the two investment sectors, particularly in the downward movements that probably show a contagion effect between the two investment segments, and which will probably require the definition of risk policies in the near future.

In methodological terms, the analysis of short-term connections uses the estimation of multivariate models of conditioned heteroscedasticity in order to follow the time-varying dynamics generated between the two types of indices considered.

In terms of structure, Section 2 of the paper deals with the literature review, iSection 3 with a synthesis of the methodology, Section 4 with the description of the data and the presentation of empirical results, and Section 5 with the final considerations.

2 | THEORETICAL BACKGROUND

The scope of the connections between international stock markets has attracted great attention in research, with particularly emphasis being placed on the role of the main international capitalizations. In fact, this issue has been one of the most widely debated in the field of portfolio theory; namely, understanding their effect on investment diversification. In this regard, Arouri et al. (2010) argue that the performance of a portfolio

depends not only on the return and risk of the assets held in an investment portfolio, but also on the correlation and co-movement established between them, such that investors should consider including several types of assets in their portfolios.

Over the last few decades, several academic studies have analysed the interdependencies and convergences established between international stock markets in the short run and in the long run. The analysis of short-term relationships has been used to study contemporaneous and lagged interdependencies, using mainly market returns to ensure the satisfaction of certain statistical properties of the series; namely, stationarity (Gabriel & Manso, 2014; Gabriel & Pazos, 2017; Lee & Jeong, 2014; Tudor, 2011). As regards long-term relationships, several academic works have analysed the verification of common stochastic trends between stock markets, considering the respective series in levels, for sample periods of several years (Babečský et al. 2012; Gabriel & Pazos, 2017; Hussain & Saeed, 2016).

Early studies on this theme led us to believe that the different markets were fundamentally guided by factors of a specific order, providing an excellent vehicle to diversify international investment (Bertoneche, 1979; Branch, 1974; Grubel, 1968; Ripley, 1973). Subsequently, in the work of Roll (1988), some situations of interdependence across international equity markets were identified.

Numerous research studies have concluded that the links between equity markets have changed considerably in recent decades, looking mainly at phases of economic and financial integration and, in particular, during periods of high market volatility, especially when stock markets crash (Bekaert et al. 2007).

In this sense, Arshanapalli et al. (1995) argue that the stock market crash of October 1987 strongly influenced convergence among international equity markets, substantiated in the increase of interconnections, making markets more predictable, partially rejecting the hypothesis of market efficiency, according to which prices in an efficient capital market should follow a random walk and reflect all the available and relevant information (Fama, 1970).

In turn, Gabriel and Manso (2014) and Mandigma (2014) recognized the dominant role played by the US stock market which, as the main international capitalization, drives movements in other markets around the world, helping to anticipate their behaviour.

More recent research works have highlighted the influence of certain market episodes in the convergence of equity markets; namely, those characterized by high volatility. An example of this is the role played by the recent global financial crisis.

Applying Granger's causality tests and impulse response analysis, Tudor (2011) concluded that the links between some stock markets in central and eastern Europe and the US market were strengthened with the

emergence of the crisis. Considering the same methodology, Gabriel and Manso (2014) and Mandigma (2014) obtained the same conclusion when analysing the connections between international markets in different geographies. Aloui et al. (2011) concluded that during the global financial crisis there were extreme movements between markets in the US, China, India, Brazil, and Russia. However, for Dajcman et al. (2012) the interconnectivity and transmission mechanisms among the stock markets of Austria, France, the UK, and Germany is time varying, and the global financial crises have accentuated equity linkages, but in a non-uniform way.

The occurrence of extreme events, such as during the period related to the global financial crisis, leads to a decrease in the benefits associated with the diversification of investment (Gabriel & Manso, 2014; Lee & Jeong, 2014).

To analyse the short-term relationships across equity markets, several research works methodologically resorted to multivariate approaches; namely, the autoregressive vector and conditioned heteroscedasticity models. Gabriel and Manso (2014), and Mandigma (2014), among others, applied the former approach in their works. The latter approach was applied in the works of Aragón and Salvador (2011), Dajcman et al. (2012), and Lee and Jeong (2014), who sought to analyse the variable nature of short-term links between stock markets.

The study of long-run relationships among equity markets has also given rise to multiple research works, mostly considering the cointegration concept and the approaches of Johansen (1988) and Pesaran et al. (2001).

Applying the first methodological approach, several studies have identified a certain degree of integration among international equity markets (An & Brown, 2010; Babecký et al. 2012; Caporale et al. 2009; Raj & Dhal, 2008; Samitas & Kenourgios, 2011; Syriopoulos & Roumpis, 2009; Tripathi & Sethi, 2012). Conversely, but also applying the first approach, several studies did not identify signs of integration between stock markets (Karim et al. 2010; Majid & Kassim, 2010; Olusi & Abdul-Majid, 2008). Considering the second approach, other studies have confirmed the hypothesis of integration among the studied equity markets (Hussain & Saeed, 2016).

The diversity of results obtained in the literature for long-run relationships is strongly justified by the factors of time and geography (Bley, 2009).

The attention that academics and investors have given to the topic of sustainable investment has prompted the appearance of several indices dedicated to sustainability. In 1990, the first sustainable index was created, and was given the name Domini 400 Social Index (DSI). Over the last decade and a half, several indices dedicated to socially responsible investment have been created, notably the Dow Jones

Sustainability Index (DJSI), the FTSE4Good Index, E. Capital, Ethibel, Humanix, Jantzi, KLD Analytics, and Morgan Stanley Capital International (MSCI). From this last series, we highlight the index dedicated to the theme of climate change, which includes companies that are part of the so-called low-carbon economy, and which was launched by Morgan Stanley in June 2020.

As mentioned above, although sustainable investment is attracting the interest of investors and academics, few scholarly works have explored this topic. Of the works consulted on sustainable investment, the vast majority have emphasized its performance in comparison with conventional investment, with a small number of studies addressing the behaviour of sustainable indices, among which we highlight the work of Roca et al. (2010) and Gabriel and Pazos (2017). The first studied the short-term links between several sustainable indices, and concluded that these have intensified over time. The second studied the dynamics generated in the short and long term between environmental segments, and concluded that they interact very closely in the short term, similar to conventional indices. This relation was found in long-term stochastic trends among the segments studied.

As can be seen, within the scope of the literature devoted to short and long-run relationships between international stock markets, there is a research gap regarding socially responsible investment, and the authors are unaware of any studies that consider the segments linked to the low-carbon economy. We address this gap below.

Taking into account the literature, we define the following research hypotheses:

Hypothesis 1: *The indices of the low-carbon economy sector converge in the long run with conventional indices.*

Hypothesis 2: *The indices of the low-carbon economy converge in the short run with conventional indices.*

3 | METHOD

3.1 | Cointegration test

Pesaran et al. (2001) proposed the ARDL test, also called the Bounds Test, which has some advantages, especially in the way it deals with the issues of endogeneity and the order of integration of the variables. In the first case, the test makes it possible to avoid the problem of endogeneity, by assuming all variables are endogenous. In the second case, it allows accommodating variables of different orders, $I(1)$ and $I(2)$, bypassing the limitations shown by other approaches reported in the literature; such as the approach of Johansen and Juselius (1989).

The ARDL model takes into account a one-period lagged error correction term, which does not have restricted error corrections. Hence, the ARDL approach involves estimating the following Unrestricted Error Correction Model (UECM):

$$\Delta Y_t = a_{0Y} + \sum_{i=1}^p b_{iY} \Delta Y_{t-i} + \sum_{i=1}^p c_{iY} \Delta X_{t-i} + \sigma_{1Y} Y_{t-1} + \sigma_{2Y} X_{t-1} + \varepsilon_{1t}, \quad (1)$$

$$\Delta X_t = a_{0X} + \sum_{i=1}^p b_{iX} \Delta X_{t-i} + \sum_{i=1}^p c_{iX} \Delta Y_{t-i} + \omega_{1X} X_{t-1} + \omega_{2X} Y_{t-1} + \varepsilon_{2t}, \quad (2)$$

where Δ is the difference operator, p represents the lag structure, Y_t and X_t are the underlying variables, and ε_{1t} and ε_{2t} are serially independent random errors, with mean zero and finite covariance matrix. In Equation (1), where ΔY_t is the dependent variable, the null hypothesis is $H_0: \sigma_{1Y} = \sigma_{2Y} = 0$, that is, there is no long-run equilibrium relationship, and the alternative hypothesis is $H_1: \sigma_{1Y} \neq 0, \sigma_{2Y} \neq 0$. Similarly, in Equation (2), where ΔX_t is the dependent variable, the null hypothesis is $H_0: \omega_{1X} = \omega_{2X} = 0$, that is, there is no long-run equilibrium relationship, and the alternative hypothesis is $H_1: \omega_{1X} \neq 0, \omega_{2X} \neq 0$ (Pesaran et al. 2001).

3.2 | Multivariate models of dynamic conditional correlation

In order to analyse the contemporary and lagged dynamic links established between the two types of variables, two multivariate models of conditioned heteroscedasticity are estimated; the GARCH-BEKK and GARCH-DCC variants, seeking to ensure parsimony in the estimates produced while meeting the usual Akaike and Schwarz information criteria.

The GARCH-BEKK model, proposed by Engle and Kroner (1995), avoids the non-negative conditional covariance matrix. The quadratic form for the conditional covariance overcomes the problem of ensuring the positivity of the conditional covariance estimate. This model is an evolution of the GARCH-Vech model, and is a more parsimonious alternative to multivariate inference.

The bivariate GARCH-BEKK (1,1) parametrization can be written in the following way:

$$H_t = CC' + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} u_{1,t-1}^2 & u_{1,t-1}u_{2,t-1} \\ u_{2,t-1}u_{1,t-1} & u_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' H_{t-1} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}. \quad (2)$$

In this equation, A_{ki} , $i = 1, \dots, q$, $k = 1, \dots, k$, and B_{kj} , $j = 1, \dots, q$, $k = 1, \dots, k$ are $N \times N$ matrices. As long as the

constant term CC' is positive, H_t is guaranteed to be non-negative.

Engle (2002) and Tse and Tsui (2002) proposed the multivariate model of dynamic conditional correlation (GARCH-DCC), which differs from other models, such as the constant conditional correlation model, proposed by Bollerslev (1990), by allowing large time-varying covariance matrices to be estimated.

Estimating the GARCH-DCC model involves two stages. In the first stage, univariate GARCH models are applied to each of the series. In the second stage, the standardized residuals obtained in the first stage are used to obtain the conditional correlation.

In this model, the conditional covariance matrix is written as:

$$\Sigma_t = D_t \Gamma_t D_t, \quad (3)$$

where:

$$D_t = \text{diag} \left(\sqrt{h_{11,t}}, \sqrt{h_{22,t}}, \dots, \sqrt{h_{nn,t}} \right), \quad (4)$$

$$\Gamma_{t+1} = [\text{diag} (Q_t)]^{-1/2} Q_t [\text{diag} (Q_t)]^{-1/2}, \quad (5)$$

$$Q_t = (1 - \alpha - \beta) \bar{Q} + \alpha u_{t-1} u_{t-1}' + \beta Q_{t-1}, \quad (6)$$

and h_{it} follows a GARCH process (1,1), Σ_t is the conditional covariance matrix and u_t is the vector of standardized values of t , Γ_t is the matrix of time-varying correlations, Q_t is a positive semi-defined symmetric matrix, and \bar{Q} is the matrix of non-conditional variance of u_t . The time-varying elements of Γ_t , $\rho_{ij,t}$ are:

$$\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t} + q_{jj,t}}}, \quad (7)$$

where $q_{ij,t}$ is the element of Q_t . For the positive definition of Γ_t , the matrix Q_t must be defined positive. It is expected that $\alpha \geq 0$, $\beta \geq 0$, and $\alpha + \beta < 1$, for the conditional correlation matrix to be defined positive.

4 | DATA AND EMPIRICAL RESULTS

4.1 | Data

We use daily data for a period of approximately five years, involving five global indices of the so-called low-carbon economy and two conventional global indices, namely:

- MSCI AC Asia Pacific Climate Change Index (AP) – it accommodates assets of large and medium-sized

companies, five developed markets, and nine emerging markets in the Asia and Pacific region, intended to represent an investment strategy linked to the transition to the low-carbon economy;

- MSCI ACWI Climate Change Index (ACWI) – it accommodates assets of large and medium-sized companies, 23 developed markets, and 26 emerging markets, intended to represent an investment strategy linked to the transition to the low-carbon economy;
- MSCI Emerging Markets Climate Change Index (EM) – it accommodates assets of large and medium-sized companies, from 26 emerging markets, intended to represent an investment strategy linked to the transition to the low-carbon economy;
- MSCI Europe Climate Change Index (EU) – it accommodates assets of large and medium-sized companies, from 15 developed European markets, intended to represent an investment strategy linked to the transition to the low-carbon economy;
- MSCI World Climate Change Index (W_CC) – it accommodates assets of large and medium-sized companies, from 23 developed markets, intended to represent an investment strategy linked to the transition to the low-carbon economy;
- United States of America (USA) Index – it accommodates assets of large and medium-sized companies in the North American market. It consists of 627 references and covers about 85% of the capitalization of that market;
- World Index (W) – it includes assets from 23 countries, related to large and medium capitalizations of different geographies. This index incorporates 1,650 references, which represent about 85% of the capitalization of each country.

The data series analysed in this study were provided by MSCI, for the time period 2014–20, which translates into 1572 daily observations.

To investigate the possible presence of long-run equilibrium relationships among climate indices and

conventional indices, we consider all the series in levels. To analyse the dynamics established between the two investment segments, in the short run, we first calculate the logarithmic returns of the selected indices by applying the expression $\ln(P_t/P_{t-1})$, in which P_t and P_{t-1} represent the daily values of a given series, on days t and $t-1$, respectively.

4.2 | Descriptive analysis and stationarity

We begin by appreciating the evolution of the seven series in terms of levels and logarithmic returns. The time series graphs are shown in Figure 1. On the left side we plot the evolution of these series in levels, and on the right side the graphs of the return series are shown, in the sample period between September 2014 and September 2020.

Graphical analysis of the indices allows us to conclude that they present somewhat similar patterns of behaviour, although in all cases the values of the indices have evidenced strong variations throughout the period studied, especially as a result of the pandemic, as of the second quarter of 2020. However, despite the oscillations that have occurred, the graph of the return series is mean reverting with volatility clustering.

Examining Figure 1 helps us to follow the evolution of the series, but provides no understanding of the dynamics established between them. In the next section, we go deeper into this topic of analysis.

To obtain summarized information about the logarithmic returns of the selected indices, the summary statistics are presented in Table 1.

An analysis of the main descriptive statistics allows us to conclude that only the index related to European markets displays negative average daily profitability. All return series show signs of deviation from the normality

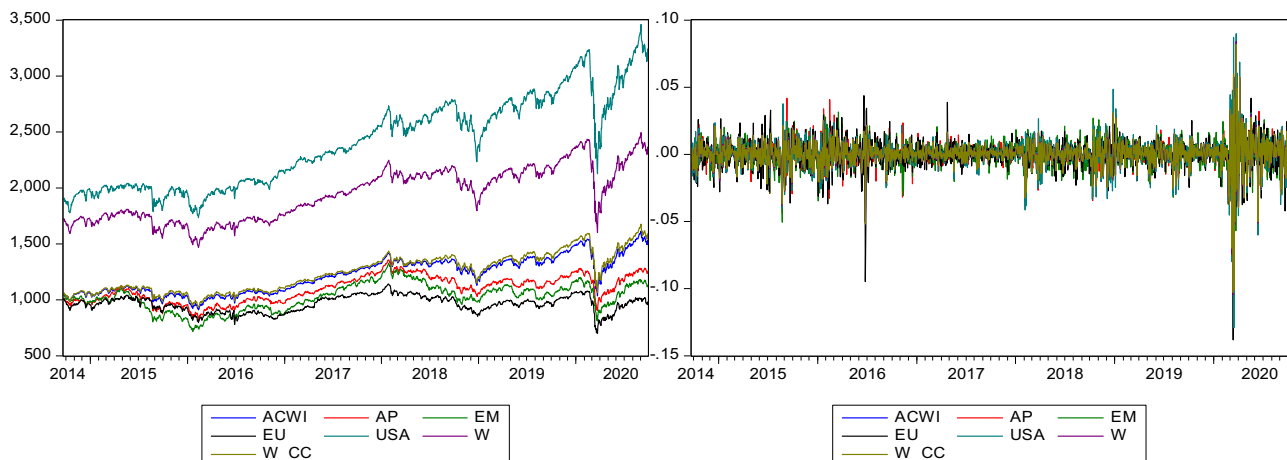


FIGURE 1 Evolution of the series

TABLE 1 Descriptive return statistics

	ACWI	AP	EM	EU	USA	W	W_CC
Mean	0.00023	0.00014	0.00005	-0.00002	0.00034	0.00020	0.00026
Median	0.00049	0.00037	0.00040	0.00036	0.00030	0.00047	0.00054
Maximum	0.07898	0.05247	0.05587	0.08172	0.08983	0.08406	0.08187
Minimum	-0.09874	-0.05702	-0.06777	-0.13815	-0.12922	-0.10441	-0.10287
Standard deviation	0.00941	0.00888	0.01013	0.01130	0.01157	0.00975	0.00974
Skewness	-1.52501	-0.35796	-0.69549	-1.62736	-1.11575	-1.52821	-1.48713
Kurtosis	26.10820	7.69118	8.45819	23.74462	25.24306	27.46365	26.84437
JB (Prob.)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
ADF (Levels)	(0.87567)	(0.80984)	(0.67704)	(0.58284)	(0.91610)	(0.84142)	(0.88688)
ADF (Prof.)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)

Note: values in parentheses indicate the *p*-value.

TABLE 2 Summary of the bounds test results

Variables	USA		World	
	ARDL model	F statistic	ARDL Model	F statistic
ACWI	(2;3)	2.611297	(4;1)	0.929457
AP	(2;4)	2.319249	(3;4)	2.273656
EM	(1;4)	2.317280	(2;4)	2.372117
EU	(3;3)	2.319928	(3;3)	1.153706
W_CC	(3;3)	2.956619	(1;4)	2.649120

Notes: in the study of bivariate relations, the critical values of the Bounds Test of 6.84 and 7.84 were taken into account for the lower limit $I(0)$ and the upper limit $I(1)$, respectively, according to the values presented in table C1.iii, provided by Pesaran et al. (2001).

hypothesis, taking into account the skewness and kurtosis coefficients. The negative skewness of all the return series is evidence of negative overall performance. For each part, the kurtosis coefficients indicate the fatness of the tails of the distribution around the mean. In this case, all the kurtosis coefficients are greater than three, such that we may conclude that the studied series are not normally distributed. This conclusion is confirmed by the Jarque–Bera test of normality, which rejects the null hypothesis of normality at 1% significance level.

To test the null hypothesis of the non-stationarity of all the series, both in terms of levels and logarithmic returns, the Augmented Dickey–Fuller (ADF) unit root test was employed. Table 1 shows the results of the ADF test. In each case, the ADF test statistics for the series in levels are statistically insignificant, such that we accept the null hypothesis (H_0) that the series has a unit root. However, the series is stationary at first difference, $I(0)$, at the 1% significance level.

4.3 | Empirical results

To analyse the presence of long-run equilibrium relationships among the indices representing the low-carbon

economy and traditional indices, the ARDL model was applied, considering the pairs formed by both.

In order to apply the approach of Pesaran et al. (2001) it is necessary to ensure that the series involved do not present an integration order greater than one. Considering the results of the ADF tests (presented previously in Table 1), we may conclude that all seven series in levels are non-stationary, thus ensuring the necessary compliance with the base condition.

As regards the application of the methodological proposal of Pesaran et al. (2001), we consider different formulations of the ARDL model and different lag length. The Akaike and Schwarz information criteria were then used to select the appropriate model for each bivariate case. The null hypothesis of no cointegration is examined via the *F*-statistic, reported in Table 2.

The *F*-statistic is then compared with two critical limits (upper-bound and lower-bound), provided by Pesaran et al. (2001). In theoretical terms, the null hypothesis of no cointegration is rejected when the *F*-statistic is higher than the lower-bound limit; if the *F*-statistic is between the two bounds' limits, the test is inconclusive; if the estimated statistic is less than the lower bound limit, the null hypothesis is accepted and it is concluded that cointegration exists.

Table 2 shows the optimal lag length structure for each bivariate model, taking into account the Akaike and Schwarz information criteria, as well the *F*-statistic, which provides an idea about the joint null hypothesis that the coefficients of the lagged variables are zero.

In view of the results generated from the Bounds Test for the 1% significance level, we may conclude that the null hypothesis of no cointegration of the various bivariate situations are not rejected in relation to either the US index or the world index, such that these results are not in line with those obtained for conventional indices in earlier published studies, namely those of An and Brown (2010), Babecký et al. (2012), Caporale et al. (2009), Hussain and Saeed (2016), Piesse and Bruce (2010), Raj and Dhal (2008), Samitas and Kenourgios

(2011), Syriopoulos and Roumpis (2009), and Tripathi and Sethi (2012). We therefore believe that our results have important implications from a theoretical and practical point of view in the context of finance literature.

In terms of theory, the failure to verify long-term equilibrium relationships between the two investment segments leads us to believe that the assumptions established by the market efficiency hypothesis remain valid, in the sense of Fama (1970), insofar as they do not reveal any possible prediction of the behaviour of the indices in the long run.

From a practical point of view, the results of the Bounds Test lead to the non-validation of Hypothesis 1, which implies rejecting the assumption of long-term equilibrium relationships between the pairs formed by the two index segments. This suggests that behaviour investment in the low-carbon economy does not depend significantly on transversal market factors, namely those related to side effects caused by long-term movements in conventional indices. If similar movements occur, the autonomy of the low-carbon economy indices would be restricted insofar as it would be possible to generate some type of forecast, starting from movements described by traditional conventional indices. Failure to verify a common stochastic trend between the two investment segments has important practical implications. With regard to formulating an investment diversification strategy, considering assets that represent the low-carbon economy may prove to be very important, as it improves the possibilities of risk diversification at the international level.

In order to analyse the time-varying nature of the conditional correlations generated in the short term between low-carbon indices and conventional indices, bivariate models of conditioned heteroscedasticity were estimated generated from the series of logarithmic variations, after confirming the respective stationarity, considering the results of the ADF tests, reported in Table 1.

Analysis of bivariate relationships involved estimating two models (GARCH-DCC and GARCH-BEKK) for several specifications; namely, incorporating the asymmetric effect, the lag length, and the distribution

of errors. As none of these specifications showed the ability to improve the estimated performance, we opted for its simpler versions of the models.

The GARCH-DCC model tended to perform better, considering the results of the Akaike and Schwarz information criteria. However, it was not always possible to comply with the specific assumptions of this model, especially with regard to guaranteeing that the conditional correlation matrix will be positive semidefinite, which forced the use of the GARCH-BEKK model.

Table 3 reports the summary of the estimated models for each bivariate case, generating from the interaction established between the low-carbon and conventional segments, for contemporary and lag scenarios.

Based on the estimates of the conditioned heteroscedasticity models, Figure 2 was constructed, which allows the variable correlations between the low-carbon indices and the conventional indices over time to be followed, considering two different scenarios. On the left, contemporary dynamic conditional correlations between the indices studied are presented. In order to provide additional information for investors and market players, we wished to know whether the conventional indices contain information about the future behaviour of low-carbon indices. Thus, the lagged correlations are shown on the right, considering the lag of one day in the closing values of the conventional indices in order to understand the consequences that previous oscillations in these indices have on low-carbon indices.

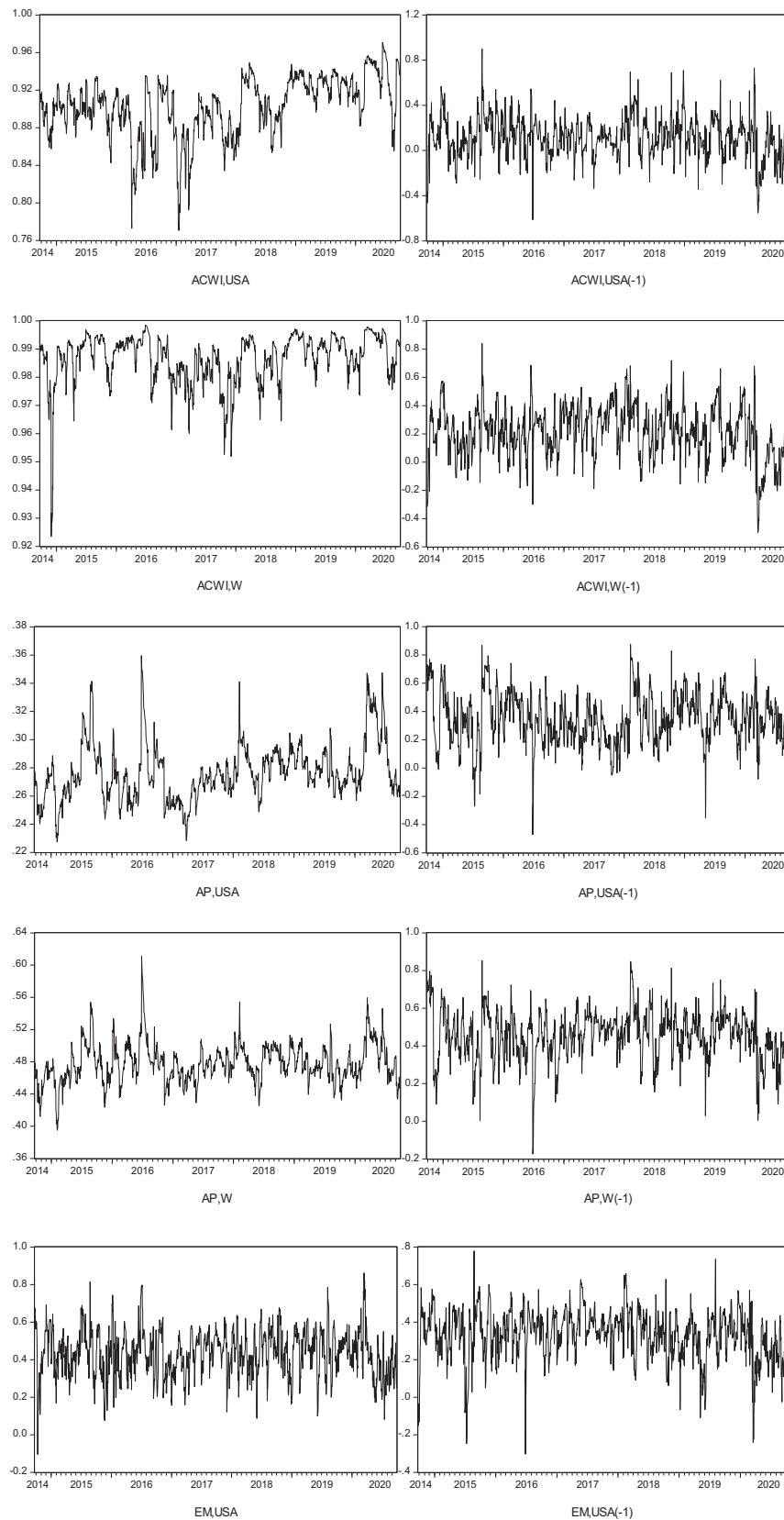
Regardless of the scenarios considered (contemporary and lag), the conditional correlations showed strong fluctuations during the sample period, refuting the typical environment of high dynamics and volatility in stock markets.

In all cases the contemporary conditional correlations between low-carbon and conventional indices were positive, with the respective behaviour strongly reflecting the emergence of the crisis caused by the pandemic, with the stock markets starting to fall

TABLE 3 Summary of the GARCH models

	USA		World	
	Contemporary analysis	Lagged analysis	Contemporary analysis	Lagged analysis
ACWI	GARCH-DCC (GJR)	GARCH-BEKK (Diagonal)	GARCH-DCC (Normal)	GARCH-BEKK (Scalar)
AP	GARCH-DCC (EGARCH)	GARCH-BEKK (Diagonal)	GARCH-DCC (Normal)	GARCH-BEKK (Diagonal)
EM	GARCH-BEKK (Scalar)	GARCH-BEKK (Scalar)	GARCH-BEKK (Indefinit Matrix)	GARCH-BEKK (Scalar)
EU	GARCH-DCC (EGARCH)	GARCH-BEKK (Diagonal)	GARCH-DCC (Normal)	GARCH-BEKK (Diagonal)
W_CC	GARCH-DCC (Normal)	GARCH-BEKK (Scalar)	GARCH-DCC (Normal)	GARCH-BEKK (Scalar)

Notes: this table presents the summary of the models selected for each bivariate situation, taking into account the fulfilment of the specific assumptions of the models as well as the results of the Akaike and Schwarz information criteria. Considering the multiplicity of estimates produced, the authors chose not to include them fully in the present work, showing only the dynamic conditional correlations generated from the estimates produced by the models in question. If the reader is interested in accessing these estimates, they are available from the authors upon request.

**FIGURE 2** Dynamic conditional correlations

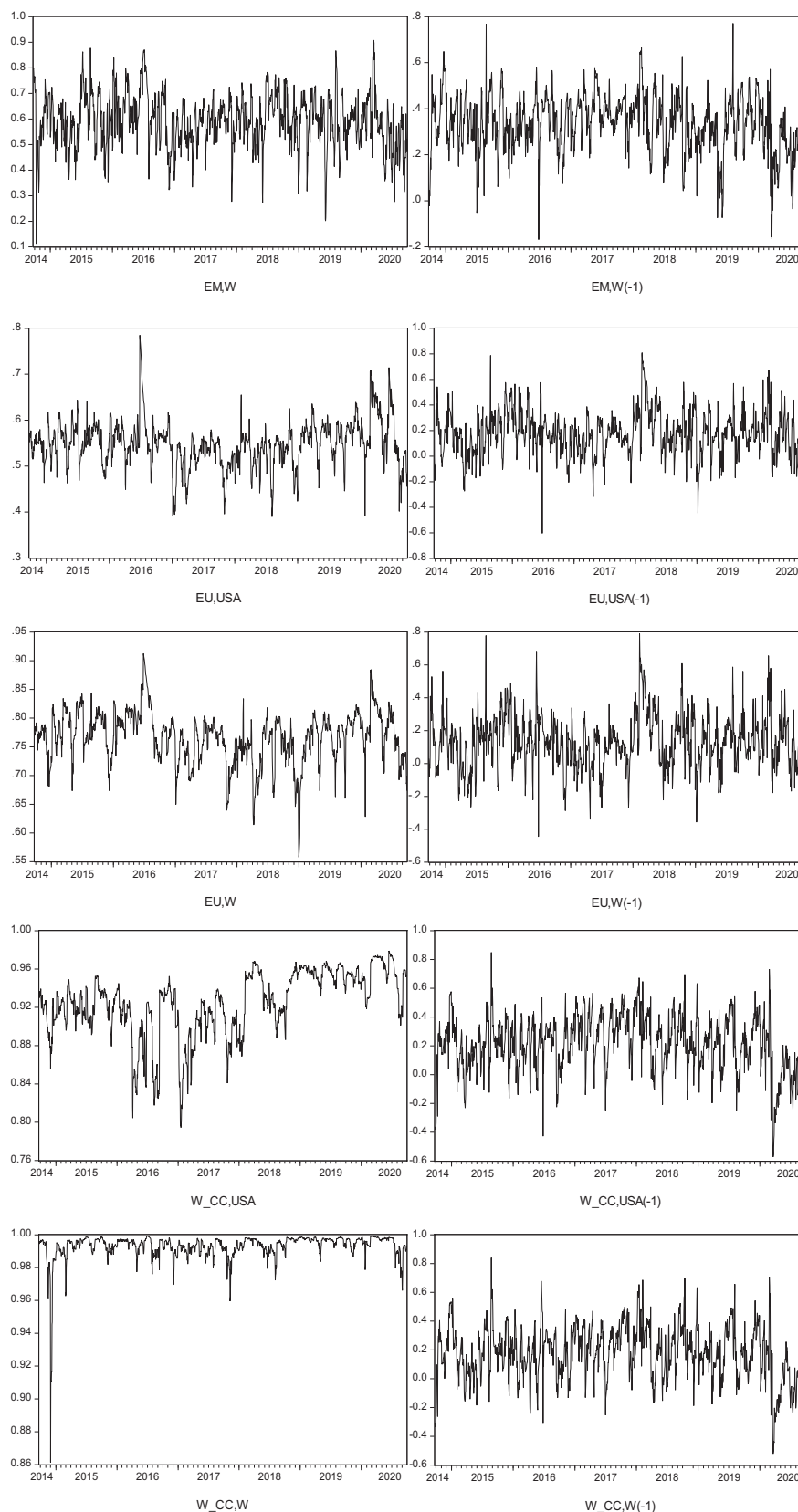


FIGURE 2 (Continued)

sharply in March 2020. The least intense correlations were recorded in pairs formed with the representative index of the Asia and Pacific region. The most intense

correlations are associated with the ACWI and world-wide indices, often exceeding the 0.95 level. These intense levels can be justified by the fact that the two

stock market segments maintain a very close relationship, especially during periods marked by turbulence, in which the markets tend to follow very similar paths in the short term.

When considering the one-day lag scenario, it is possible to conclude that, as with contemporary relationships, the correlations showed high variability over time in a very dynamic path with positive and negative values, except for the pair formed between the index of emerging markets and the United States of America index. The negative values of the conditional correlations may indicate that at certain times conventional indices produce negative effects on low-carbon indices, suggesting that the former is a risk factor for the latter.

In view of the contemporary scenario, the intensity of conditional correlations has decreased, although there is still a certain degree of association between the two types of indices. This suggests that the behaviour of low-carbon investment is not indifferent to the events experienced in stock markets in general, which generate transversal effects with repercussions on the different types of assets. Changes in conventional indices therefore seem to have implications for the sustainable segment. In view of the results obtained, it seems plausible that in the short term the two investment segments studied are characterized by relatively similar behaviours, which supports Hypothesis 2. This situation seems to suggest that transversal market factors overlap with segment-specific factors, and that investment in the low-carbon economy is greatly exposed to market events. In this sense, this investment segment does not seem to differ significantly from the situation that characterizes conventional equity markets, considering the results of other research works such as those of Dajcman et al. (2012), and Lee and Jeong (2014).

In view of the high intensity of conditional correlations in the short term, low-carbon indices and conventional indices follow very similar paths regarding their respective behaviours, which is a reason to believe that the mechanisms generating the profitability of both are based on a common basis. This proximity is likely a consequence of the globalization process in the financial sector, which favours proximity, interaction, and contagion between markets. This makes it difficult for investors to decide on a possible investment diversification strategy in the international context.

5 | FINAL THOUGHTS

Studying links across international equity markets has given rise to a considerable number of research undertakings in finance. The non-statistical confirmation of links between markets expands the range of

possibilities for international investment diversification. Several studies on this topic have reported a decrease in the possibilities of diversifying investment in the international context, especially in times of market turbulence. However, the overwhelming majority of works have favoured conventional indices, based on purely financial logic, to the detriment of the representative indices of the low-carbon economy.

In this research work, we develop a first comprehensive analysis of the links between low-carbon equities and conventional equities. Five indices representative of the low-carbon economy and two conventional indices were selected in order to analyse the dynamics between them in the short and long-run time horizons.

To investigate the possible existence of long-run equilibrium relationships between the two investment segments, we used the approach of Pesaran et al. (2001) to each of the bivariate situations. The results of the Bounds Test allow us to conclude that in none of the cases were long-run equilibrium relationships identified, such that the behaviour of equity indices does not seem to be determined by transversal market factors. On the contrary, the behaviour of the indices seems to depend mainly on idiosyncratic factors. This situation allows us to conclude that the representative indices of the low-carbon economy offer room for a possible investment diversification strategy in the international context, and can be an alternative to conventional indices, which are based on a purely financial logic.

To analyse the dynamics established in the short term between the two investment segments, bivariate models of conditioned heteroscedasticity (GARCH-BEKK and GARCH-DCC) were considered, which allowed conditional correlations to be estimated in order to follow the dynamics established between the indices over time for the contemporary and lagged scenarios. As regards the first scenario, it was possible to conclude that the two investment segments displayed very similar movements. As for the second scenario, there was a generalized reduction in the intensity of the conditional correlations. On the other hand, at certain times, negative correlations are obtained, lending credence to the hypothesis that conventional indices play the role of risk factors for their low-carbon counterparts.

This work has important implications for equity investment and financial regulation. First, the results obtained show that the representative indices of the low-carbon sector respond to conventional indices very quickly, making the possibilities of diversifying investment in the short term complex, similar to what happens with conventional indices. Conversely, in the long run, low-carbon indices and conventional indices are not integrated, such that investors can find in the low-carbon sector a good opportunity to diversify investment on a global basis as an alternative to traditional

equity investment, simultaneously combining financial objectives with sustainability issues.

Second, this study is also relevant to market regulators. The results obtained show that the two investment sectors exhibit identical behaviour, with this similarity being particularly accentuated in downward movements. Contagion can be defined as the impact of extreme negative events. In this context, taking into account the results obtained, which highlight the high degree of correlation between the investment segments studied, it seems plausible to believe that there are real conditions of contagion risk between them. This situation requires the effort of regulators to ensure adequate policies on a global scale designed to limit the risk of contagion across equity segments and to prevent the occurrence of major crisis events. These regulation policies can be subdivided into two categories. First of all, it seems pertinent to adopt policies at the company level, such as reducing their credit exposure risk, creating contingent credit lines, and minimizing payment delays. In addition, we believe it makes sense to adopt market-oriented policies, such as improving the information made available to investors, minimizing asymmetric information in financial markets, and controlling adverse selection. We also believe in supporting services and the connection of information and communication technology (ICT) systems in order to reduce possible disruption situations. Finally, the measures developed for sustainable equity investment must go hand in hand with macroprudential policies in order to mitigate general systemic risk to financial markets.

This study can be also extended to other industries and sustainable investment and further years, and may even analyse the effects of external shocks such as the effects of the crisis. In future research work we will delve deeper into the subject under consideration, adopting a new methodology based on the model of structural autoregressive vectors and on the concept of spectral causality, thereby allowing a more detailed analysis of the dynamics between the two investment segments.


ACKNOWLEDGEMENTS

The first author recognizes and is grateful for the financial support received from FCT – *Fundação para a Ciência e Tecnologia* (grant UIDB/04007/2020). Lozano is grateful to the Junta de Castilla y León and the European Regional Development Fund (Grant CLU-2019-03) for the financial support to the Research Unit of Excellence “Economic Management for Sustainability” (GECOS) y al IME.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

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How to cite this article: Gabriel, V.M.D.S., Lozano, M.B. & Matias, M.F.L.I. (2021) The Low-carbon Equity Market: A New Alternative for Investment Diversification? *Global Policy*, 00, e13024. <https://doi.org/10.1111/1758-5899.13024>